UNIVERSITY OF CANTERBURY

An arrangement of tablets for supporting collaborative learning

by

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in the
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Declaration of Authorship

I, AUTHOR NAME, declare that this thesis titled, 'An arrangement of tablets for supporting collaborative learning' and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

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Abstract

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This thesis details the design and implementation of a system that uses tablets to create a platform for co-located collaboration. Previous research has demonstrated the potential of touch tables for facilitating collaborative work, and this system seeks to create a similar working space and determine whether similar collaborative benefits can be achieved. An evaluation is carried out comparing the tablets system to a laptop and a touch table in terms of facilitating collaboration. The tablets system is shown to have similar collaborative potential to the touch table. This offers a cheaper, more accessible alternative to touch tables for facilitating computer-supported collaborative learning.

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Chapter 1

Introduction

Educational research has shown that collaboration, and cooperative work, can be beneficial for students' learning [5] and has therefore been widely adopted by schools. This research will investigate how existing technology can be best used to support this learning paradigm. A common technology that can be found in New Zealand classrooms are tablets, and using these in a more effective way could lead to more successful learning outcomes. This thesis designs a system of using networked tablets to create a shared workspace similar to that of touch tables. These tabletop computers have previously been shown to have potential for facilitating effective collaborative learning. A laptop, touch table, and the networked tablets system are compared to determine whether using multiple tablets alongside each other can have benefits for collaborative digital work.

The rise of collaborative learning has led to the emergence of computer-supported collaborative learning (CSCL), a research area which has emerged in the last 20 years as a response to the possibilities offered by technology to support this learning pedagogy [6]. Alongside this area of research and development we have seen the proliferation of tablet computers such as the Apple iPad. Some studies indicate that the use of tablet computers in schools is beneficial to student learning and can make collaboration easier [7]. However the form factor of these devices does not allow more than one person to use an application at a time, something which can hinder collaborative work efficiency [7]. This project aims to take advantage of the proliferation of tablets in the modern classroom, using them to form an ad-hoc, large working surface in order to enable students to work together, as well as individually. So far in the CSCL literature there has been relatively little research done on collaborative systems that can be used in the form of a single screen display or a large, shared, multi-screen display.

The proposed working surface will have similar characteristics to a large touch table display (see Figure 1.1). These types of displays, and user interaction with them, have been studied

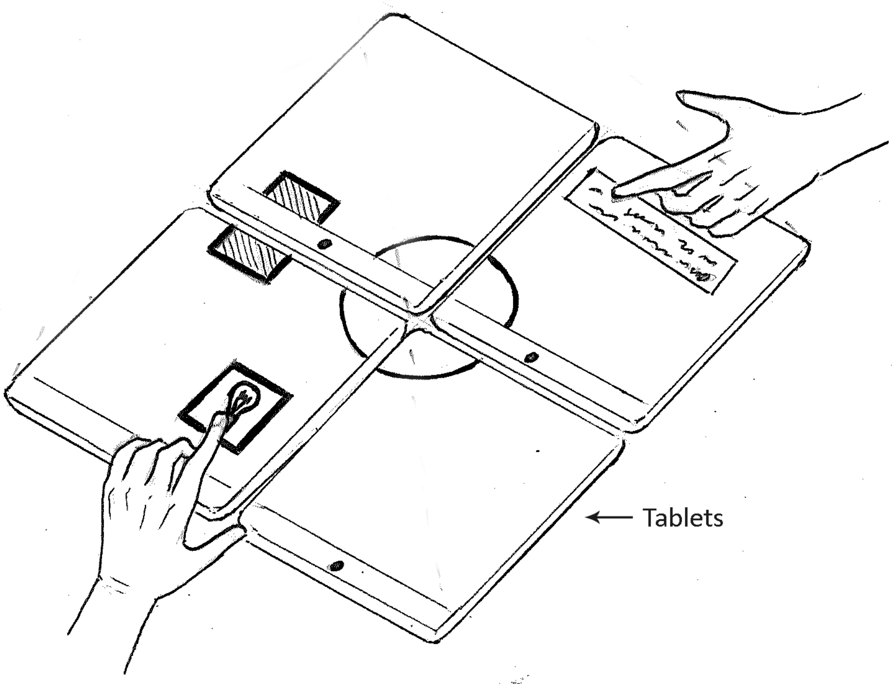

FIGURE 1.1: Sketch of planned networked tablets system

in detail, and there is evidence to suggest that they encourage collaboration more than alternative computer systems (e.g. laptops). While researchers have shown that touch tables do demonstrate good potential for use across the education sector they are currently too expensive, under-developed and under-supported for classroom use. Touch tables would require these factors to be improved on before being useful to the majority of schools [1]. It is hypothesised that using tablets to form a similar workspace would provide the benefits of collaborative work that have been observed with touch tables, while retaining the affordability, flexibility and alternative uses of a tablet computer.

While there has been some research into how tablets could be used to form larger work surfaces for co-located work, this research has so far been focused on the technical aspects of creating this technology. No studies have yet tested the hypothesis that networked tablets could provide similar benefits to collaborative work as touch tables. There is a need for research which tests the potential application of this new technology in a school environment and how it compares to other forms of computer-supported collaborative learning for encouraging and improving student collaboration.

This thesis will contribute research knowledge in the CSCL sub-field of tabletop computing, helping to determine the factors which make co-located collaborative work on digital devices succeed or fail. It will describe the design of a system and application that uses multiple networked tablets, using an iterative interaction design approach. The thesis will offer a range of design concepts generated from initial research into user needs. These concepts will inform the design of a working prototype with which to perform an evaluation of the interface and hardware. This evaluation will seek to provide an answer as to whether a networked arrangement of tablets is a suitable substitute for a touch table in the classroom. From this process of creation and evaluation design guidelines for future systems will be provided.

To do so the following questions will be answered:

- Is the tablets system usable? What are the differences in interaction styles and possibilities between the tablets and the touch table?
- Is the *quantity* (as defined by an existing behavioural framework) of collaborative behaviour the same across tablets and touch table?
- Is the *quality* (as defined by an existing behavioural framework) of collaborative behaviour the same across tablets and touch table?

The thesis will offer a prototype collaborative application using networked tablets, and will evaluate this to determine the potential for further research into this style of platform. It will build on prior research to provide more data on the comparison between touch tables and alternative technologies to support collaborative learning. It will provide design guidelines for future networked tablets systems, based on the results of the evaluation and design process.

Chapter 2

Background

This thesis explores how networked tablets in a grid layout can be used to improve collaboration between students in a classroom, similar to the enhanced collaboration that has been shown with touch tables. This chapter will explore the existing literature relevant to the topic, divided into several sections. *Collaborative and cooperative learning* focuses on the social psychology of collaboration, reviewing why, when and how collaborative work is successful at leading to individual learning outcomes. It guides the design of the system in this thesis to best realise these benefits. *Computer supported collaborative learning* and *mobile learning* focus on what existing literature has found regarding the contribution technology can make to improved collaboration. *Touch tables in education* and *touch tables interactions styles* reviews research into touch tables that is applicable to this situation due to the similar use and interaction this solution will offer. *Ad-hoc collaboration with mobile systems* explores existing solutions similar to what this thesis aims to create. *User evaluation* reviews types and methods of user evaluation used in similar projects, namely in research on touch tables. This helps in informing the design of the user evaluation presented at the end of this thesis.

2.1 Collaborative and cooperative learning

Collaborative learning is the practice of working with other people on a problem or project to attain a specific educational objective [8]. Collaboration is thought to be effective due to the social interactions that occur within the group and can result in each individual achieving a higher level of learning than if they were to work alone [8]. There are two main theories regarding the role of social interactions on learning and these led to the current theory of collaboration. The Piagetian approach considers that group members learn through conflicts due to differences in the opinions and strategies of others [9]. The Vygotskian approach considers that the internalisation of the information and skills of others, such as other group members, is the cause of this learning [10]. In order to analyse collaborative work we can use these approaches to find key points which can be observed and coded for evaluation. Although slightly different in their approach, both lead us to the same elements which together form collaborative learning: (1) presence of conflict and requirement for negotiation; (2) the importance of coordination and interactivity and (3) communication amongst the group [11].

In practice, collaborative learning requires the members of the group to fulfil certain roles in order to work together efficiently, which is something that cannot be relied upon to occur spontaneously if students are placed into groups [8]. Cooperative learning is a methodology of collaborative learning which aims to solve this problem, whereby the teacher organises students and teaching to maximise the benefit of collaborative work [12][5]. Cooperative learning offers a range of methods for teachers to do this such as: student team learning (basing marks off both the individual scores and the aggregate group score on a test); Jigsaw method (setting specific roles for each student in the group); learning together or group investigation. Although all of these methods vary they have the commonality of making both teams and individuals accountable for their learning [5]. The ways in which cooperative learning solves some of the problems associated with collaborative learning provide guidance when designing the interface and content for this system.

There is strong evidence for the academic benefit of cooperative learning, with many studies having been conducted since its rise to popularity in the 1960s [13]. Johnson et al conducted a meta-analysis in 2000 [13] and concluded that cooperative learning can significantly increase student achievement when compared to individual learning and competitive learning. The meta-analysis took data from studies that covered a variety of age ranges, however 66% of the studies analysed had subjects in primary or intermediate school, which is the age range targeted in this thesis. The results also found that many of the methods used in cooperative learning were robust and were effective across a wide age range. Slavin (1983) [14] argues that existing studies of cooperative learning which show positive learning solely by evaluating the group work or group result do not represent individual learning achievement. They therefore cannot constitute evidence that cooperative learning is beneficial for individual learning. By only looking at group work it is possible that one or two high-achievers in the group may be doing most of the work and leaving the lower performing academic students out. However Slavin did find that when looking at cooperative learning studies that incentivised both group and individual results, that there was positive educational gain for individual students. A more recent meta-analysis by E. Kyndt et al [15], in 2013, demonstrated results in agreement with these prior findings.

2.2 Computer supported collaborative learning

Computer supported collaborative learning (CSCL) is a field which explores the potential of computers to enhance collaborative learning [16]. The aim of CSCL is not to simply move traditionally paper-based activities to the digital world, but to use the computing platform to improve the organisation and management of the group [11]. It also seeks to support a more diverse range of ways that the groups can create knowledge, especially through the creation of digital artifacts [17][16]. P. Dillenbourg warns that there is a temptation in CSCL to over-script collaborative activity [17]. Because the designer can use the capabilities of software to regulate large amounts of the group interaction, it is possible to exert too much influence. This influence can reduce what would have been considered collaborative learning to something more akin to regular learning with individuals carrying out particular tasks at particular points in time.

The education sector has a history of adopting computing technologies, with the widespread introduction of tablet computers (e.g. iPads) being one of the most significant changes over the past five years [18]. One of the reasons for this may be that tablet computers have encouraged collaboration between students more than laptops and desktop computers [7][19], possibly due to their ability to provide a horizontal working surface rather than a vertical one [20]. Tablet computers are also very easy to pass between people, enabling several users to easily collaborate together [21]. However, while they may increase the potential for collaborative digital work, it is often observed that only one student can feasibly use a tablet at a time due to the small size [7].

2.3 Mobile learning

Mobile learning is a relatively new field that has begun to attract interest since the popularisation of mobile devices. It aims to provide students with seamless learning and the ability to learn anywhere at anytime. Studies have shown that around half of an adult's learning occurs while not at home or in the office [22], and mobile learning has the ability to support this. Due to their portability and growing popularity in schools, tablet computers can be used as mobile devices to provide information anywhere, anytime. Prior studies have explored both the technical development of software to support collaboration, and the effectiveness of mobile learning. In their 2012 review, W. Wu et al [23] found that 58% of papers evaluated mobile learning effectiveness and 32% focused on designing a mobile learning system.

In 2001 A. Danesh proposed one of the earliest mobile learning systems [24], the Geney game, which allowed students to learn via a mobile game on PDAs. In 2004 G. Zurita [11] evaluated non-technological collaborative learning activities to determine how mobile learning could solve some of the problems associated with collaborative learning. These early papers have

FIGURE 2.1: Mobile learning example using tablets

led to a growing field of mobile learning which favours the view that a correctly designed mobile solution can lead to positive educational outcomes through allowing learning in different contexts (outside the classroom) and by enriching conversation and collaboration [25].

One study of particular interest by Y. Huang et al (2014) combined cooperative learning with mobile learning [26]. They combined a Jigsaw method based cooperative learning approach with the use of the Google+ social networking platform on a tablet. This showed higher academic achievement (measured through test scores) for students when compared with a control group that used the same computer technology to support individualised learning.

The tablets used in this project can be considered mobile devices, however they do not suffer some of the same restrictions as other mobile devices, such as small screens and lower processing power.

2.4 Touch tables in education

Since around 2001 [27] touch-sensitive tabletop devices have been investigated for their ability to allow co-located collaborative work. However a majority of this research has been focused on the technological aspects of developing these tables and the means of interacting with them [28][1]. Some prior studies such as the study by S. Do-Lehn [29] have found no significant relationship between the amount of collaboration around a touch table compared to alternatives. However, in this study collaboration was only measured through "Learning gain from partners" which may have measured knowledge transfer, rather than more accurate measures of collaboration such as negotiation of ideas which concern knowledge building within the group.

Indeed the authors conclude that collaboration seemed qualitatively better on the touch table in spite of the differences in the quantitative analysis. A majority of studies, however, have shown that touch tables allow easier collaboration and coordination while working [1]. For example, O. Shaer (2011) found that a touch table condition facilitated more effective collaboration than single or multi-mouse laptop conditions [30].

S. Higgins et al conclude in their 2011 review [1] of touch tables in collaborative learning environments that touch tables do seem to significantly improve collaborative digital work. However he cautions that these results are hard to generalise due to the varied technologies and software used in the evaluations. The link between this increased collaboration and actual improvement on test scores is unclear [28] and some studies have found that touch-tables do not always produce significant learning gains [29].

An important aspect that has been highlighted by Y. Rogers et. al. [28] is that when evaluating touch tables in the context of education it is important to not solely consider the learning outcomes in the form of pre- and post- test scores, as this fails to provide insight into how or why collaboration occurred. A more valuable alternative is to evaluate the type of collaborative mechanisms and interactions happening around the table, as this can indicate how positive the collaborative activity is. The authors outline behaviours that should be measured as part of evaluating collaborative learning. These behaviours are based on the key aspects of collaboration established in previous education and psychology research and are: making and accepting suggestions, negotiating, and joint attention and awareness.

There has been a range of research into how touch tables support the mechanisms of collaboration. Of particular interest has been whether these surfaces facilitate improved equity of participation (a sign of quality collaborative behaviour [8]) over alternatives. Multiple studies have investigated equity of participation on touch tables with most results showing that physical participation is more equitable on touch tables than alternatives [30][31][32]. Studies have also compared the equity on multi-touch to single-touch tables, with most results showing no difference in physical or verbal equity between the two [33][34]. However, some studies do provide conflicting results, which show a difference in physical participation equity [31]. However, in this study participants were required to move to a particular area of the touch table to use the single-touch input, which may have led to more inequitable participation when compared to the multi-touch condition.

Other researchers have investigated the potential for touch tables to facilitate collaborative work through increased discussion. Multiple studies have found that touch tables can increase task related talk and discussion [33][20][30]. This discussion of ideas is a very important element of collaboration and the influence of these social interactions on the cognitive process is thought to be the core reason for collaborative learning's success at achieving improved learning outcomes [8].

FIGURE 2.2: Touch tables in the SynergyNet classroom, a experimental classroom built to explore the use of touch tables in education [1]

2.5 Touch tables interaction styles

When designing for table top displays, designers need to be aware of the existing notions and skills that users have built up over many years of collaborating around tables. As such, existing research into interaction with touch tables has been informed by previous research on collaborating around physical tables and horizontal work surfaces with paper [35]. Some research into paper based collaboration provided insight into collaborative work that would inform the design of interfaces and software in the future. J. Tang observed [36] through a collaborative drawing space activity in 1991, several key points of importance in a shared workspace: hand gestures, the process of creating artefacts, concurrent access to the drawing space, and different functionality should be allowed for different users simultaneously.

S. Scott et al [37] built on these findings and developed guidelines for supporting co-located collaborative digital work. In addition to the findings by J. Tang they suggest allowing seamless transitions between personal and group work, supporting transitions between table top collaboration and external work, and to support the use of physical objects.

Orientation of interface elements has been known since at least 1989 [38] to be one of the significant usability challenges for designers creating touch table applications or similar interfaces. With a number of people using the same surface, the orientation of interface elements can have an impact on usability. People also use orientation to establish personal space (putting objects in front of themselves), and to communicate (orienting text/image towards the group or other members of the group for discussion). R. Kruger et al [35] suggest allowing free rotation of all objects on the screen so that users are able to manipulate them and use their orientation to support traditional and familiar social interactions.

C. Remy et al [39] offer a design language for the design of tabletop systems in their 2010 paper. They suggest: making touch tables circular to allow for uniform access to the digital space for users, allowing a variety of input devices, using tangible objects to increase interactive possibility, and keeping track of what each user has created to enable later evaluation.

An study by K. Ryall et al [40] explored the effects of both table and group size on an activity performed on a multi-touch table. The study found that while users preferred larger screen sizes for the task it did not improve completion time. K. Ryall et al does point out however that simply increasing screen size does not increase the amount of information which can be displayed, as the resolution of the screen must also increase for this to be possible – a potential limiting factor in their study. This has implications for the use of tablet devices in a similar context, as most tablets feature high-resolution screens capable of displaying large amounts of information in a relatively small space.

2.6 Ad-hoc collaboration with mobile systems

Some research has been done into how mobile systems can be used to create ad-hoc collaboration. However these papers generally focus on the technological development of these tools. K. Hinckley et al [41] created a system in 2004 for linking multiple tablet computers using stylus gestures across devices (see Figure 2.3). They called this "stitching" and it allowed an arbitrary number of users to join the networked group, enabling novel interactions. In 2007, researchers at the Hasselt University created a system that allowed multiple PDAs to interact with the same data on a virtual canvas by using a camera to track the PDAs and orient them to the canvas. While potential use cases were explored no user evaluation of the solution was done [42].

K. Lyons et al [2] provided a user evaluation comparing two systems similar to the "stitching" system in 2009. The authors compared the use of tablet computers and small laptops in an ad-hoc display. They found tablets to be more suitable for the conditions of ad-hoc collaboration, that users could effectively use cross device interactions and that the multi-tablet composition was used effectively as a unified display. In 2012 Li and Kobbelt [43] built a system to use tablet computers to form a larger work surface through use of a shared digital canvas. They used a ceiling mounted camera to track the tablets, making the tablets act as windows to the digital canvas. The "Phone as a pixel" system [44] used multiple devices to form a large display. This was done with a server for hosting the devices, and a camera that recognised colours which were displayed on the screens of the target devices. Using this information to locate the devices the server displayed the correct portion of an image on each device. However, this restricted the system to a static layout of devices, as the devices were not being tracked continuously. Similar to this, in 2011 the MIT media lab released a video showing the Junkyard Jumbotron [45]. This enabled devices to connect to a web page and be oriented on a virtual canvas by taking a photo of the device layout while they were displaying a tracking marker.

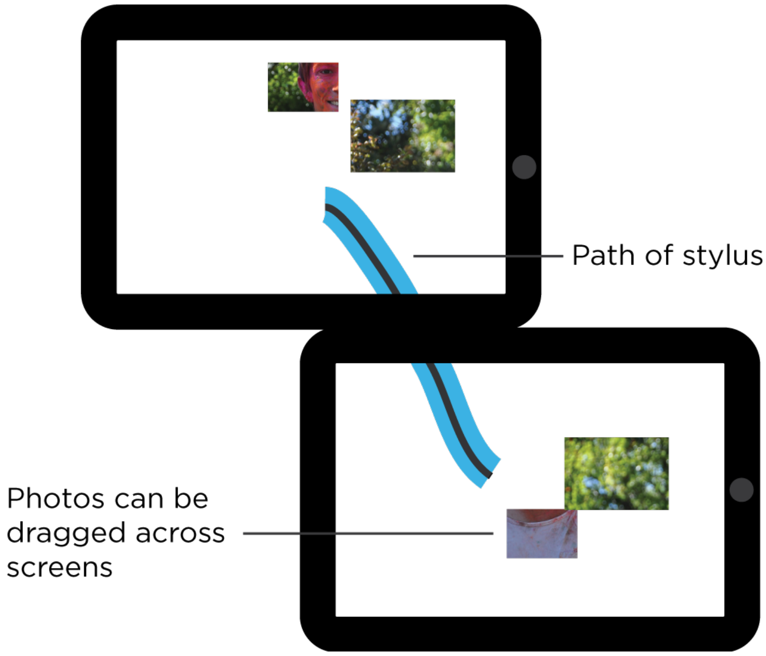

FIGURE 2.3: "Stitching" devices with pen actions (illustration based on the paper by K. Lyons et al [2])

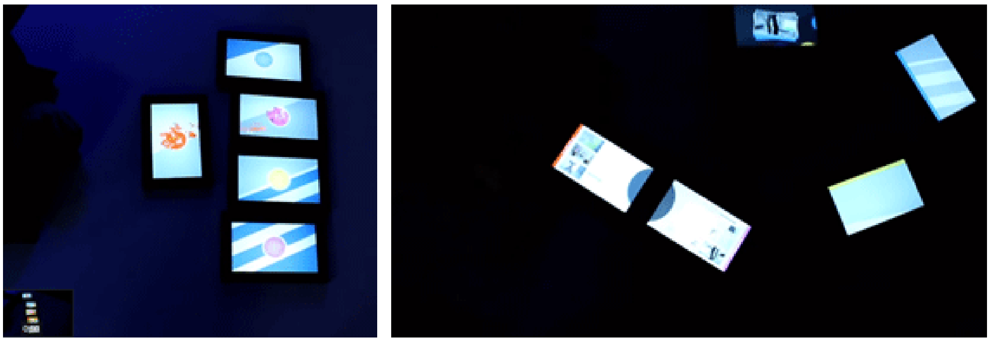

FIGURE 2.4: Game showing virtual workspace (left) and file sharing through drag'n'drop across devices (right) [3]

This also limited the system to static device layout. In 2012 Blackberry demonstrated Confetti (see Figure 2.4), an application for meetings which provides easy file sharing and interaction between Blackberry devices [3]. No evaluation or information on the system further than a video of the technology demonstration has been published as of writing.

In November 2014 researchers at Konstantz University's HCI group published a paper and accompanying open source software, Huddlelamp (see Figure 2.5)[4]. Huddlelamp offers a way in which tablets can interact with one large virtual canvas through a web browser. In addition to this, Huddlelamp offers a Javascript API which can be used to create objects on the canvas that can be rotated/scaled/moved reducing development time. The project also provides gesture functionality using a tracking camera, allowing users to move objects from screen to screen without touching the glass of the tablet. In this thesis the HuddleLamp technology will be used to build a prototype application, allowing development to focus on the creation of

FIGURE 2.5: Huddlelamp displaying a map [4]

the specific application to encourage collaboration, without requiring the development of an entirely new system for networking the tablets.

2.7 Spatial interaction between mobile devices

In 2010, S. Greenberg et al introduced the idea of proxemic interactions, which change and adapt depending on spatial relationships [46]. Research done on touch table interaction (as well as regular paper tabletop) highlights the different usages of table spaces, for example: space close to a user being personal workspace and the center being public space. Through combining these observations with the idea of using the spatial relationships between devices we can inform the design of the tablets system, allowing users to work together using these familiar interactions.

N. Marquardt et al [47] points out that that sharing files and information between current devices can be difficult, requiring many steps to transfer. This transfer of information is an important part of collaborative work. The authors offer suggestions to make this process far simpler through proxemic interactions. For example: icons on borders of devices which provide a visual link to nearby devices, through which files can be transferred.

2.8 User evaluation

The system created in this thesis requires an evaluation to test usability and learning/collaborative benefit. Existing literature in similar areas can help provide guidance on suitable evaluation methods and techniques.

Many evaluations of existing touch table and ad-hoc collaboration systems are based on measuring the usability of the solution by assesing subjective measures such as user preference [2][48]. These papers offer guidance on how a usability evaluation of this system could be conducted.

There have been a number of studies conducted on touch tables in a collaborative education/learning environments which are especially helpful in guiding the design of the study which will be conducted in this thesis. These studies generally use qualitative observation methods like coded video analysis. The coding of observational data is usually done with regard to a psychological framework of learning and collaboration such as those mentioned in the *collaborative learning* section above [28][33]. Some of these studies combine this qualitative analysis with more formal measures, such as time to complete task or quality of output (measured through test scores)[1][49].

There has also been research conducted that evaluates the quantity and quality of the collaboration afforded by touch tables in a non-educational setting [20][50][51]. These studies combine an evaluation of the solution using user preference questionnaires, with observational coding of actions and speech to analyse the type of social interaction taking place.

2.9 Research opportunity

Research shows strong evidence for the benefits of collaborative learning. There is also good evidence for the potential of touch tables to improve and motivate collaborative learning. Combining this with research into the creation and design of ad-hoc mobile systems to encourage collaborative learning is an under-explored area of HCI research.

While there has been research into the effectiveness of touch table computers in aiding collaboration and learning, there has so far been little research on how effective tablets could be in creating similar learning benefit. There has been some research into creating systems for ad-hoc interaction, but there is little research into determining their effectiveness in supporting collaboration and educational uses.

Ad-hoc tablet displays may also better support cooperative learning than touch tables, as they can be used as both an individual research tool and as part of group work. These ad-hoc tablet displays could allow for more seamless transitions between individual and group work. This could therefore present design opportunities in using tablets to support this style of collaborative learning.

Chapter 3

Design Process

In this thesis the design process began with user understanding and needs analysis, followed by concept generation and prototyping to create and refine the interaction and interface design. Testing was conducted to evaluate the interface and answer the research questions. This chapter sets out the design process and the steps that were taken to arrive at the final solution. This design process enabled solutions to be designed that were appropriate for the context and users - in this case teachers, students, school staff and parents.

The target age range for the project was students between eight to thirteen years old, in Years Five to Eight. While the project aimed to offer a solution that would be suitable at all levels, research was focused on the senior primary school years as students at this age are more capable of articulating feedback.

3.1 Overall process

The design methods adopted in the user understanding phase were: casual observations in a collaborative classroom environment, cultural probes [52] and interviews with teachers. Using these research methods provided a range of insights which informed the design of the final system.

The needs analysis enabled an understanding of the context in which this system will be used and the needs and requirements of each stakeholder group. Following needs analysis, concepts were generated and rapid paper prototypes were made in order to refine the system and the user interaction with it. These rapid paper prototypes aimed to test the interface usability early in the process through informal user testing. A prototype system was then designed that includes the core functionality necessary to answer the research questions and to determine the potential of this type of system. An envisaged future system was also designed which would incorporate teacher needs and support a wider range of learning situations. It presents a vision for future work.

The working prototype was built using the open source tracking and web API available from the University of Konstanz Huddlelamp project [4]. The Huddlelamp project allows for the networking and tracking - and therefore use in an ad-hoc display – of any device with access to the internet, meaning that the final application can be run on any mobile devices available. The software allows development of interfaces and content using Javascript and HTML5 and uses a server running node.js to perform the syncing interaction across tablets. This allowed access to a wide range of existing Javascript tools and libraries, reducing the development time and effort of building the interface.

3.2 Understanding

3.2.1 Cultural probes

Cultural probes were the first research technique employed in the process to gain a broad understanding and familiarity with the culture and attitudes of students in the target age range. These cultural probes provided inspiration for concepts and gave information on user needs and limitations that would need to be considered when designing a solution.

Cultural probes are packages of items (such as maps, postcards, disposable cameras and games) designed to inspire responses which inform the researcher about the culture of the respondents [52]. They are most effective when there is a significant cultural difference between researcher and subject or when geographical distance makes other methods of research difficult. In this case cultural probes were thought to be a suitable design research method to use with the students due to the large difference in attitudes and culture between the researcher and the young students as potential users. This difference may have made more traditional techniques such as interviewing less beneficial. Cultural probes were used to encourage the students to consider and analyse their answers by giving them time to think and explore their ideas before writing a response, and avoiding the impression that a correct answer was expected of them.

Ten probes with six activities in each package were used for this research. These activities were: Keeping a diary, writing a short story, writing about their ideal team for problem solving, taking photographs, writing captions for photographs and designing an iPad app (see Figure 3.1). The cultural probes were delivered to a local school and left with students, chosen by the teacher, for a week. The students chosen by the teacher were between 10-11 years old and all were in the same year six classroom. Seven were female and three were male. The classroom teacher provided a point of contact between the researcher and the students. At the end of the

FIGURE 3.1: Cultural probe activity sheet

week the probes were picked up from the school. All ten probes were returned. The probes had an average response rate of 80% per task. The responses to the cultural probes were analysed in depth to identify common responses and trends. The main insights are outlined below.

3.2.1.1 Cultural probe insights

Diary entry

Students were asked to complete three questions for each day of one school week. These were: "What did you do today as part of a team, group or pair?", "Did different members have different jobs? What were they?", "How did you feel about working in this team? Why did you feel like that?". These questions aimed to improve understanding of students attitudes towards group work. The following insights were drawn from the student responses:

- Fun is the main motivator for work.
- Students recognise the contribution of others and appreciate it.
- Students recognise contributions of abstract things like ideas. Illustrated by this quote:

> "He put in his idea and I put mine and we combined them."

- Students enjoy contributing to group discussion and work.
- Students identify the social benefit of collaboration - as illustrated by this comment:

> "It felt cool because we connected more."

- Individual roles in sports teams are clearly articulated and understood.
- Students are conscious of the equity of work and contribution.
- Students acknowledge that a well-run team makes the task more enjoyable.
- Students seemed to delegate tasks based on equity of work more than any other reason.
- Little consideration is put into the structure of the group or individual roles in a group. This could be affected by the lack of specialty skills at this age.

Build a team

Students were asked to complete a task sheet in which they assembled a 'dream team' to stop climate change. This team could include mythical figures, fictional characters, celebrities or friends. This activity sought to provide insight into how students approached roles within groups. The researcher drew these observations:

- Most teams consisted of friends and fictional characters such as gods.
- Many of the students did not seem to think of those in their team as having roles.
- Most students did not describe creating a team based on skills necessary to solve the problem.
- A majority of the students saw themselves as taking some form of leadership role in the group, directing and keeping everyone else on track.

Photography

Students took six photos of things relating to collaboration and technology to provide understanding of the role of each on their day to day life. The exercise produced these insights:

- Students' favourite things to do at school were not usually technology-related.
- All students had access to a laptop or iPad at home and at school.

- Students thought of outdoor, physical games when asked to take a photo of a game.

Captions

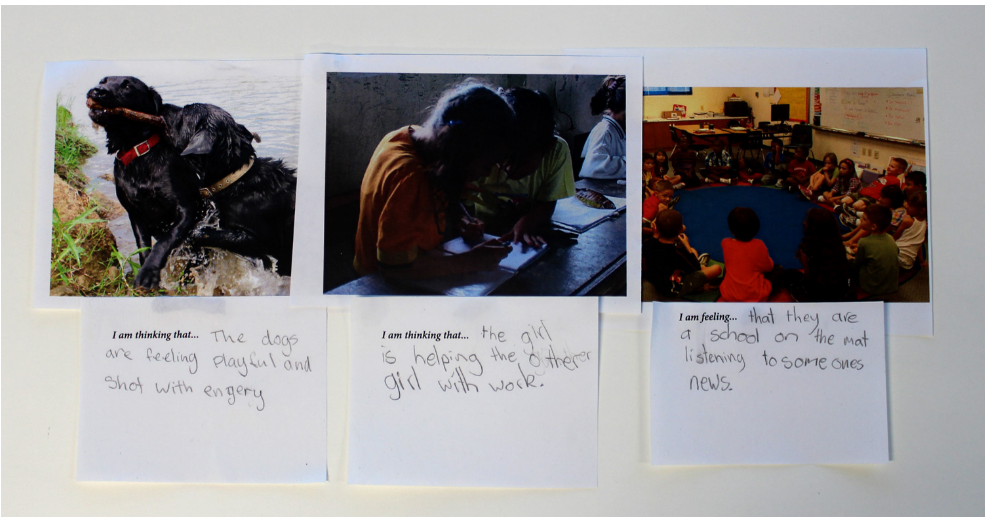

FIGURE 3.2: Photographs with captions by students

Students added captions explaining photographs of various collaboration-related situations (Figure 3.2). Insights from this task are as follows:

- Many captions showed empathy for the people and animals in the photo.
- Many students thought a photo of a pair of girls working together showed focus and interest. This possibly indicated a positive attitude toward working in groups.
- Some students thought the class sitting on the mat looked bored, possibly indicating a desire to have more interactive lessons rather than a lecture type format.

Design an app

FIGURE 3.3: Apps created by students. Left: An app to connect things, Top right: A pet browsing, purchasing and delivery service, Bottom right: A racing game

Students were given a template, basic GUI elements and coloured pens to design an app (Figure 3.3). This aimed to discover how much they intuitively understood about apps and to inspire directions for the development of the system designed in this thesis. Among the insights drawn from the students work:

- Many of the apps were very similar, which possibly suggested a natural amount of collaboration.
- Many students coloured the outside of the iPad - customising what was theirs to show personality.
- Simple UX patterns were naturally recognized and used in the design i.e. back button, status bar, keyboard.
- Apps made were usually relevant to personal interests but not potential needs - the boys being interested in games had more game-based apps, while the girls combined love of pets and travel into their apps.
- Boys' apps were mostly based on existing games, whereas girls' apps were generally more fantastical in nature.
- Students seemed to seek to give what they thought would be a "correct" answer in that they seemed to use UI elements somewhat randomly in order to use them all.

Short story

Students wrote a short story about how they and their friends saved the world from aliens. This was aimed to provide less constrained approach to understanding how students thought about collaboration and teamwork. This exercise produced relatively fewer insights.

- The activity appeared to be perceived as a writing test, with students focusing on writing an enjoyable story using correct spelling and grammar.

> "Any writing at this age becomes a spelling test."
>
> *Quote from a teacher interview*

- Many stories featured friends of the author and reflected the delegation of tasks that occurred in other activities.

The insights offered in the cultural probe were not directly applicable to the design of the application in the way interviews often are. However they provides an understanding of the culture and developmental level of the target age range, which would have been difficult to gain through other means of enquiry.

3.2.2 Teacher Interviews

Qualitative interviews were done with teachers to provide additional context and guidance to support the development of this system. Teachers are considered a primary stakeholder in this project and meeting their needs was considered to be as important as meeting the needs of the students using the system.

Five interviews were done with teachers from four schools. The schools were between decile six and ten. These teachers taught students between the ages of eight and twelve. The interviews took around 45 minutes and were semi-structured, with questions about how teachers organise their classroom, use cooperative and collaborative work and integrate digital technologies into their teaching. These interviews helped create an understanding of the classroom environment and the attitudes of students and teachers within it.

3.2.2.1 Teacher interview insights

Current Technology

- Teachers said one of the key benefits of technology is the freedom for students to research and be interested in whatever they like.

- There is a large amount of variance in technology resources both between schools and between classrooms, but tablets were common in all schools visited.
- Tablets are seen as media consumption devices, and not commonly used for production of texts or presentations.
- There are few educational apps or software based around the New Zealand Curriculum and a lack of apps which require critical thinking rather than just tapping various options.
- Physical mediums are still the most commonly used and most digital projects are usually printed or reproduced physically in some form.

Lesson structure

- Teachers generally want to minimise lecture time and maximise time spent helping individuals and small groups.
- A lot of teaching is somewhat improvised.
- Writing at primary school age is often limited by spelling and grammar.

> "Any writing at this age turns into a spelling test."

- Innovative Learning Environments (ILE) are becoming more common. An important aspect of this is allowing students to follow their own interests.
- Teachers want to inspire and engage students with lessons rather than teach to the test. This is also a core idea behind ILEs.

> "[I aim to] Create interest for children, not teaching to the test."

Collaborative Work

- Teachers want their students to talk and articulate their thoughts. Many see learning benefits in doing this.

> "So much of understanding comes from verbalising your understanding."

- Students are already encouraged to collaborate and discuss their ideas when using iPads, with teachers often limiting them to one iPad per two students.

> "I would only have one iPad between two to at least have some social aspect."

> "We visited an Australian school where it was one iPad per child and the classrooms were silent. It was terrifying."

- Making mistakes and learning from them is seen as an important part of the learning process, and working in groups can help make making mistakes easier to discuss.

> "Group work can make making mistakes easier to admit. Most kids are afraid to get something wrong but groups can help with this."

- When group work is done, teachers often create groups and group roles that are diverse to encourage a range of opinions and ensure lower-achieving students can learn from higher achievers.

> "Having roles is very important so long as they're shared."

- All teachers said that during collaborative work they move from group to group encouraging and nudging students in the right direction.
- The social benefit of collaborative work is widely acknowledged. These social aspects address key aspects of the New Zealand Curriculum (Relating to others, Participating and contributing, Managing self) [53].
- Formal cooperative group work does not seem to be particularly common. Far more common are activities that require students to work together on a project without a predefined group structure.

Technology Requirements

- Software must be very robust as the teacher is often responsible for 20 or more students so any issues or bugs can cause significant work for the teacher.
- Software needs to be simple and intuitive so that students can use it with minimal technical assistance from the teacher.
- Teachers want software that allows students to self-manage through goals, chapters or time-lines of work.
- Technology that enables sharing with the teacher for feedback and marking is viewed as helpful as it is another medium for teaching.

Technology Integration

- Teachers believe involving and improving communication with parents through technology, such as blogs and wikis, is a huge benefit both for parents and students to show their work.
- New technologies are usually implemented in the senior school and then flow down to the younger levels.

3.2.3 Personas

Personas were developed based on interviews with teachers, cultural probes completed by students, casual observations of classroom behaviours from time spent in schools and observation of video recordings of students doing collaborative work. They represent a short and relatable list of key things to consider when designing for these users.

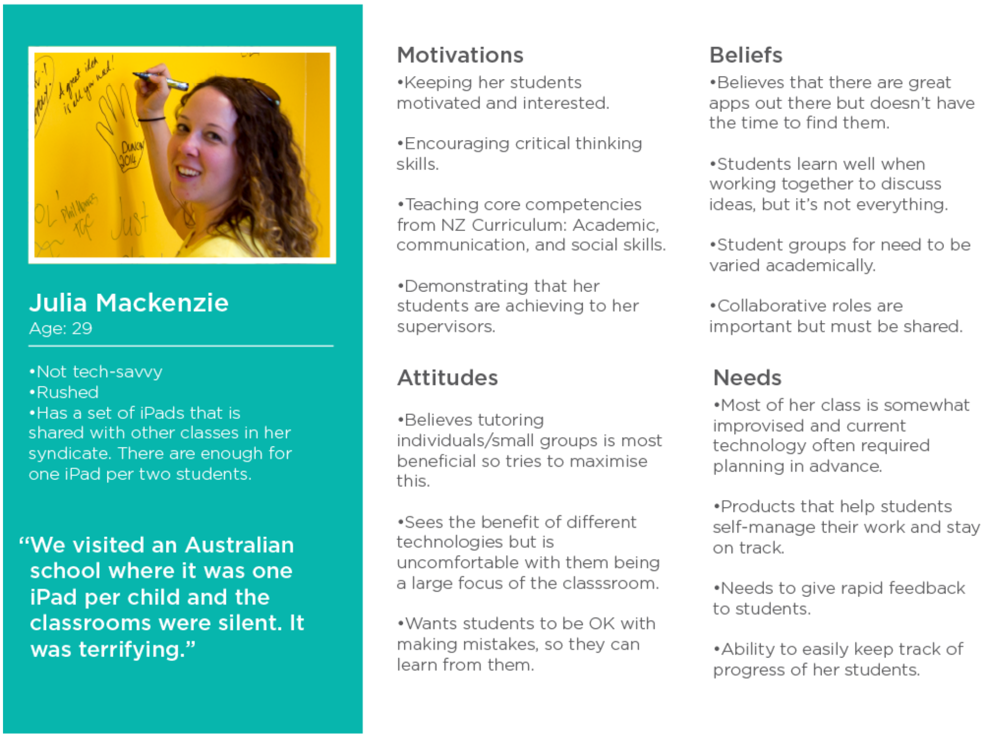

FIGURE 3.4: Teacher persona

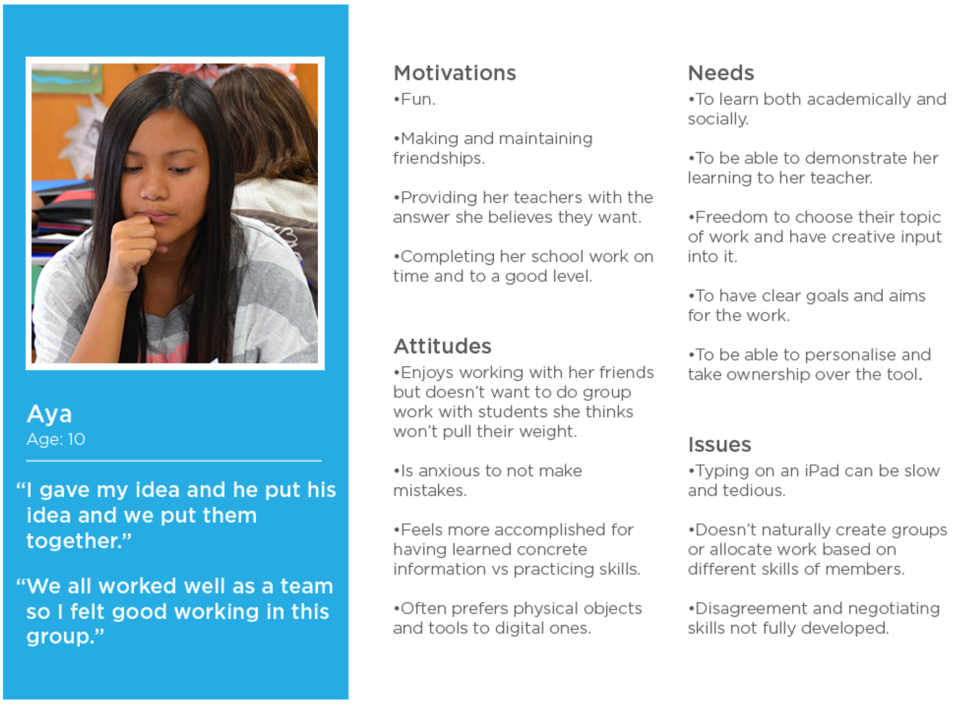

FIGURE 3.5: Student persona

3.3 Ideation

3.3.1 Attributes based on literature review

Based on the papers "Interactive table tops in education" [54], "How people use orientation on tables" [35] and "A pattern language for interactive table tops in collaborative workspaces" [39], a set of design goals was defined for a conceptual multi-tablets system. The literature-based goals were as follows:

- Incorporate gestures and UX patterns already recognised by users, such as pinch to zoom
- Align objects towards appropriate users on each tablet
- Allow users to come and go with ease
- Access to tools should not be limited – each user should have access to a range of different tools
- Allow free rotation of objects
- Allow inter-group interaction

3.3.2 Attributes based on stakeholder insights

Based on the insights from the student cultural probes and teacher interviews, potential design attributes were identified which would provide effective functionality for such a system in a classroom context. These attributes were generated both individually by the researcher and in a group brainstorming session with other HIT Lab students. In this group session participants familiarised themselves with the insights from the initial research and personas through discussion and reading, and the overall goal of creating a solution which encouraged collaboration was explained.

The group brainstorming session used a structure based on the paper "A meta-analysis of productivity loss in brainstorming" conducted by B.Mullen et al [55]. Two members of the HIT Lab NZ and the researcher each sketched six ideas privately and then discussed them amongst the group. The private sketching helped to generate varied ideas and the discussion was beneficial in developing these ideas further.

The section below outlines the ideas generated by the group session as well as the ideas generated by the individual researcher.

3.3.3 Resulting design attributes

Student usage:

- Students could have an private screen to collect information individually and then store files when in a group.
- Provide a simple flick-to-transfer mechanism between individual file storage areas both during group work and individual work. This would allow students to easily pass on anything that may be relevant to another group member.
- Roles within the group could be randomly chosen and then outlined by the application. These could also be reinforced with achievement goals being specific to the role, for example: 'Task - Collect four key quotes and two images. Consult with the group manager about what you have collected, work with others to make the group poster.'
- Students could join the group by tapping on a corresponding tablet shown in a grid on each tablet's screen.
- Students could join the group in a similar manner to stitching, by swiping across tablets [41].

- A time-line with nodes representing key stages of an activity to provide students with clear goals. Achievement of these can be either automatically determined, for example: in the case of questions with clear answers, or confirmed by other students doing the activity.
- Allow students to work on a project from home and allow individual users in this situation to pan around the canvas and have access to their individual workspace.
- As most collaborative work centres on creating some form of presentation, the interface should provide a wide range of capabilities in terms of storing research material and creating text and images. This would enable the system to be used in a range of subjects to create posters, flyers and other similar documents.

Teacher usage:

- The teacher should be provided a simple interface for tracking both group and individual completed tasks.
- The teacher should be provided with an interface to create activities so that the application can be used as part of any school topic.
- The teacher should be able to provide feedback to groups or individuals at any stage of the work.
- This interface should be able to stream a view of the group's project to the teacher to allow them to easily check up on work.

User interface:

- Tools such as the text tool could be activated by long press on the canvas, reducing the need for permanent UI elements.
- Use the tablet gyro sensor to rotate the canvas opposite to the direction of tablet movement to ensure objects stay aligned across tablets.
- Pulling tablet towards oneself could activate personal workspace, which may be required for certain activities.
- Pulling two tablets away from the middle could disconnect their actions from the group, enabling them to work closely together without affecting the rest of the group.
- Moving a tablet to the right of the group area could show the upcoming tasks/goals.

- Tilting the tablet up towards oneself or picking it up could activate a full-screen view of the personal file system stored on the application. This would be similar to picking up a stack of papers off a physical table in order to rifle through them.
- Pushing a tablet across the table to another person could hide all controls in order to focus on content (for instance, if the person is wishing to explain something to the other). This also means that there should be an option to freeze the view so that when pushing a tablet to another person the view does not update to the new position.
- The controls should be minimal so as not to increase the separating effect of the tablet bezel.
- Could have individual storage space slide up from bottom or side in a drawer menu type system to reduce use of screen space when not needed.
- A phone could be used as a small controller to control group tools like panning and zooming so that not every user can access these all the time, but they are there if needed.

3.3.4 Envisaged future system

Based on the above brainstormed design attributes, a conceptual system was envisaged. It seeks to support a range of collaborative and cooperative learning scenarios. It provides functionality for individual research to be combined with others' work in a group setting, as well as enabling novel interactions which allow intuitive navigation and use of the work space. It also supports teachers' management of student work through a central control panel.

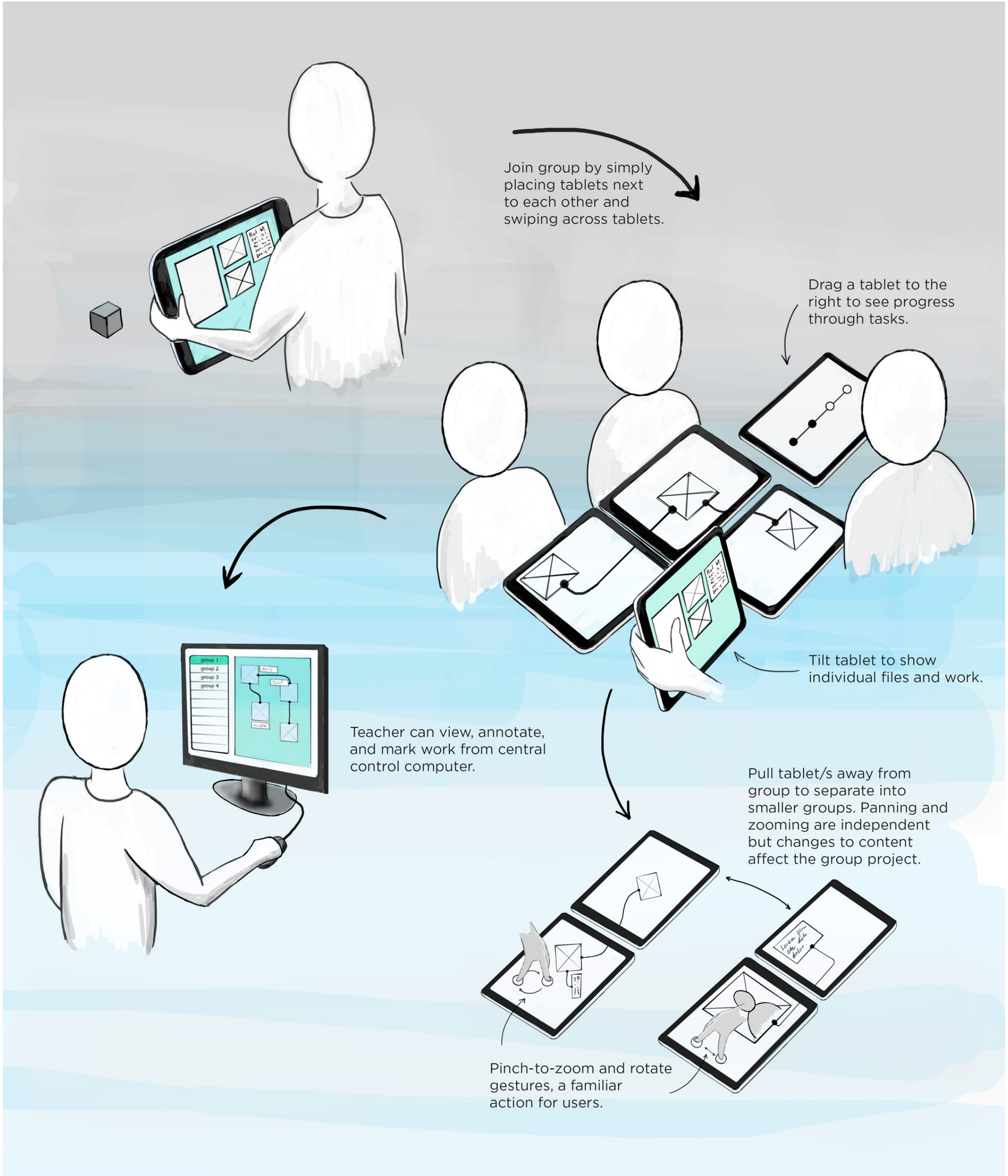

FIGURE 3.6: Final system proposal based on ideation results

3.4 Prototype concept

Having explored the design attributes that are likely to be beneficial to the users of a multi-tablet collaborative learning system, the researcher developed a basic working prototype with the core functionality required for a collaborative platform. This system was evaluated with user testing in a naturalistic, classroom-like environment to determine whether networked tablets are capable of providing similar benefit for co-located collaborative work as that provided by a touch table. From the evaluation of this prototype it can be determined whether a more fully-fledged system incorporating more of the attributes of the envisaged system is worth developing.

The main goal of this prototype was to compare a tablets system to a touch table, to provide evidence for or against their applicability in collaborative learning. The implemented system therefore looks to recreate the core functionality of the touch table, including horizontal display, multi-touch and large screen space.

3.4.1 Prototype attributes

The prototype system developed for this study incorporated the following attributes: four tablets that can be easily linked into a grid arrangement which provides similar resolution to a touch table; synchronises all aspects of a collaborative task between tablets; allows students to easily drag objects between tablets; and adjusts the display to ensure objects align, even if tablets are rotated. Also, an application enabling a collaborative student activity for use on the prototype system needed to be designed.

3.4.2 Lo-Fi Prototyping

The evaluation of the system required a collaborative task for students to complete. A concept mapping task based on that used in a previous paper was chosen for prototyping [29]. To test this learning activity for suitability in the tablets system evaluation, a rough prototype of the system and activity was created with paper. This also provided further insight into the type of behaviour that would likely be seen when collaborating around a table-like surface. Users involved in this task were both 20 years old and therefore not in the target age range, but they had no prior exposure to the system. In this prototype users were asked to drag paper images and links on the table to represent touch actions on a screen. Users wrote on these links to annotate what each one represented. The prototyping was done in pairs and users were asked to collaborate to form a group concept map. Through this prototyping it was seen that the level of collaboration was suitable, with a high level of conversation and gestures related to the task.

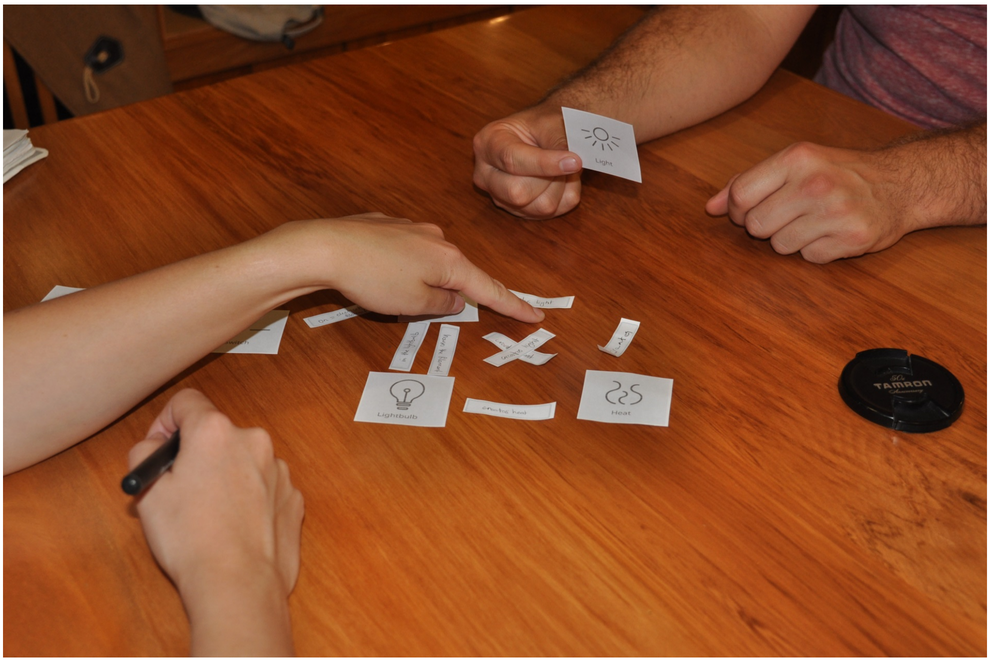

FIGURE 3.7: Paper prototype to explore concept and interaction

This task highlighted the need to ensure that the activity had sufficiently ambiguous answers. In the first prototype participants very quickly settled on what they felt was the correct answer. The task was made more difficult in the second iteration by requiring the use of all the links provided. This resulted in significantly more discussion as the task was more challenging and potential answers were less clear.

This prototype also highlighted the need to allow editing and undoing, as there were multiple occasions were new paper links had to be created in order to change annotations.

This prototyping demonstrated that the task would be suitable for stimulating collaboration with what was observed to be an easily explained and intuitive task. It informed the creation of wireframes and in time the working functional prototype.

3.4.3 Wireframe

In order to clearly describe the system that this thesis aimed to build and test, a basic wireframe was created (see Figure 3.8). The wireframe shows the means of adding and manipulating elements on the canvas. The wireframe shows the system that the thesis aimed to create, with the combined functionality explored through paper prototyping and ideation. This, as well as the user personas, helped to keep development on track an in line with user needs.

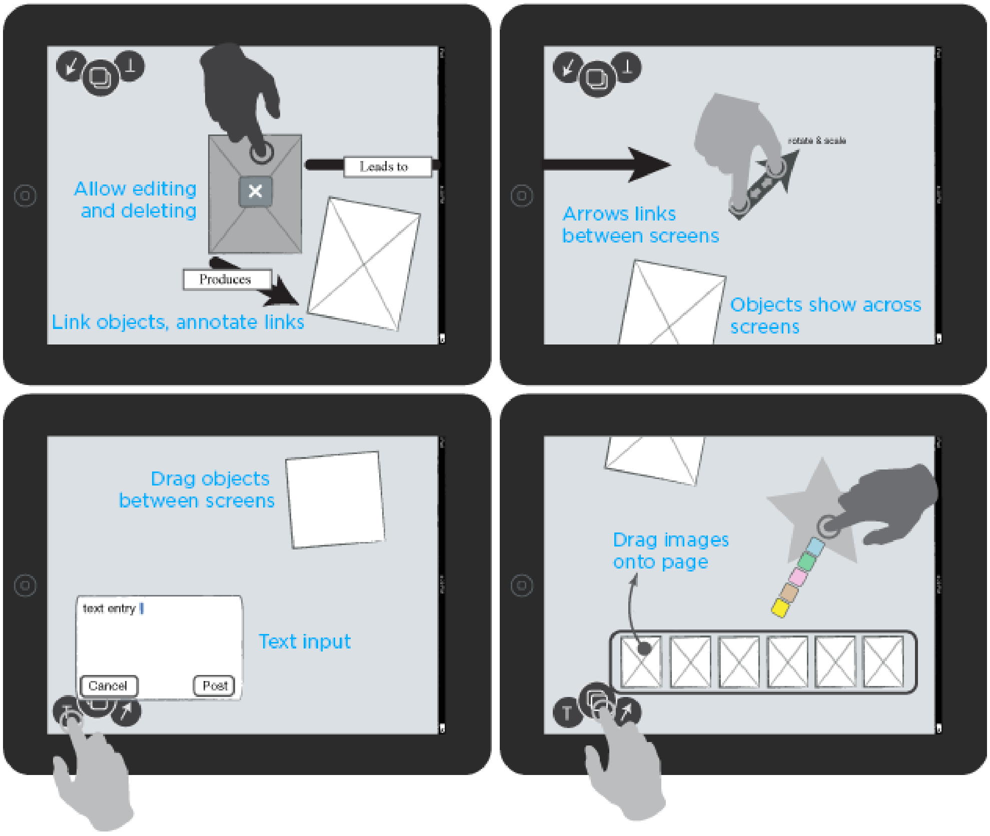

FIGURE 3.8: Wireframe of initial system concept

3.5 Specifications

The following specifications were established before beginning development. These represented the essential functionality that the working prototype required.

- No UI elements should appear on borders between tablets.
- Most aspects of the interface should be hidden to save screen space.
- The application must allow users to drag and drop images and text on canvas.
- Users must be able to add and edit text/captions.
- Users must be able to create links between images and text.
- Users must be able to edit and delete existing text, images and links.
- Images should be able to be dragged and dropped from the an "inventory" of photographs.
- The application should be responsive to display on all conditions.

- Text objects should distinguish between a word given at the start and one added by participants.
- Sound effects should be used to make it more enjoyable to use.

3.5.1 Conclusion

This section has described the process that was undertaken to design the networked tablets system, as well as the design of the software which was run, almost identically, on the touch table and the laptop. The following chapter will discuss the process of implementing a working prototype which enabled the evaluation of the design and, through this, produced results relevant to the original research questions.

Chapter 4

Implementation and Functional Prototype

This chapter describes the creation of a working, testable prototype. This prototype was created to be robust enough to be used in a classroom environment for the purpose of providing evidence to answer the research questions and conduct a user evaluation. The system created was consistent with the prototype design proposed in the previous chapter.

The system builds on the HuddleLamp[1] open source project published by R. Rädle et al [4]. HuddleLamp uses the Meteor[2] Javascript framework to synchronise the devices with a client/server network. Changes made on one tablet update the central database with this information which is then updated on the other tablets. HuddleLamp also provides a computer vision engine to track tablets and phones using the Creative Senz3D, however this functionality was not used as it was deemed not robust enough for a classroom environment.

4.1 Hardware

4.1.1 Tablets

All teachers interviewed reported the use of iPads and iPad minis, indicating that these are a commonly used device in New Zealand schools. Because of this tablets used in the project were iPads, although a Samsung Galaxy Tab was also used in the development process. These tablets provided a high-resolution screen and significant processing power. The total screen size provided by four networked tablets (the arrangement used in the study) was 492mm (diagonal) with a resolution of 2048 x 1536.

[1] www.huddlelamp.org

[2] www.meteor.com

Initially, the researcher considered incorporating hardware to track the tablets if they were moved or rotated. By tracking the tablets when they moved in any direction, the canvas could be updated so the tablet acted as a moving window onto the digital canvas. The HuddleLamp computer vision based solution was tested at the start of this development process. This tracking uses the Creative Senz3d[3] camera and the OpenCV[4] library. It locates devices based on the low IR reflectance of black bezels, enabling tracking without markers. The testing showed that the system could track at around 20fps, and in a range of lighting conditions. However, this system was found to commonly lose track of the tablets when users placed their hand between the tablets and the camera (occlusion), as well as when tablets were placed near to one another. In the context of a collaborative activity, where users were expected to move objects across tablets and would almost certainly cover the corners of the tablets, this solution had to be abandoned. This did however offer the benefit of forcing the system to be created without any technology that schools do not commonly have available.

Also, the paper prototyping exercise showed that the task did not require a large amount of work space. While constant tracking may be required for a larger digital canvas, in this task four tablets were expected to provide enough screen space to effectively complete the task.

To resolve some of the issues created by not having live tracking, a gyro sensor approach was taken. This enabled the tablets to be rotated, while rotating the image on the screen in the opposite direction. This meant that the image stayed aligned to the surrounding tablets, reducing the chance of confusion due to objects not aligning between tablets. This had the advantage of not placing any additional hardware requirements on the system, and was a more robust solution than the computer vision tracking.

4.1.2 Table

The touch table used in this study was a 850mm (diagonal), 1920 x 1080 resolution screen fitted with a PQ Labs multi-touch overlay (see Figure 4.1). This screen was powered by a Windows-based laptop, which also ran the application server. A multi-touch driver was provided for this overlay which enabled multi-touch to be registered by Windows, therefore enabling multi-touch in the application, as it was run in the browser.

In order to enable typing on this condition the Chrome extension Virtual Keyboard[5] was used. This enabled the keyboard to be shown and hidden automatically when a user tapped to select the text input tool. Although the Windows on-screen keyboard was tested it proved difficult to

[3] http://us.creative.com/p/web-cameras/creative-senz3d

[4] www.opencv.org

[5] https://chrome.google.com/webstore/detail/virtual-keyboard/pflmllfnnabikmfkkaddkoolinlfninn?hl=en

FIGURE 4.1: PQ Labs touch screen overlay fitted to large digital display

hide and show, and resulted in screen space being blocked from view. Using a virtual keyboard enabled the experience to be more similar to that of the tablets and laptop.

4.1.3 Laptop

The laptop used for the study was a Windows-based laptop with a 400mm (diagonal), 1366 x 767 resolution screen. This condition was also able to run the developed application directly from the browser with the laptop also running the application server.

4.2 Software

While all hardware components for this project were available off the shelf, custom software had to be developed. The development of the software was made easier by building on the HuddleLamp project, which was used to handle synchronisation of objects across tablets.

For this project it was decided that implementing a prototype which ran in the browser would be the best option. This meant that the same code could be run on any of the three hardware platforms without needing to install specialist software.

The most important part of the development of this software was the need for the tablets to be networked and for changes on each tablet to be quickly synced between them. Recent developments in web technologies, notably node.js[6], MongoDB[7] and MeteorJS[8], coupled with the code base provided by HuddleLamp, enabled a prototype to be built quickly which synchronises this data without requiring page refreshes.

[6]`www.nodejs.org`
[7]`www.mongodb.org`
[8]`www.meteor.com`

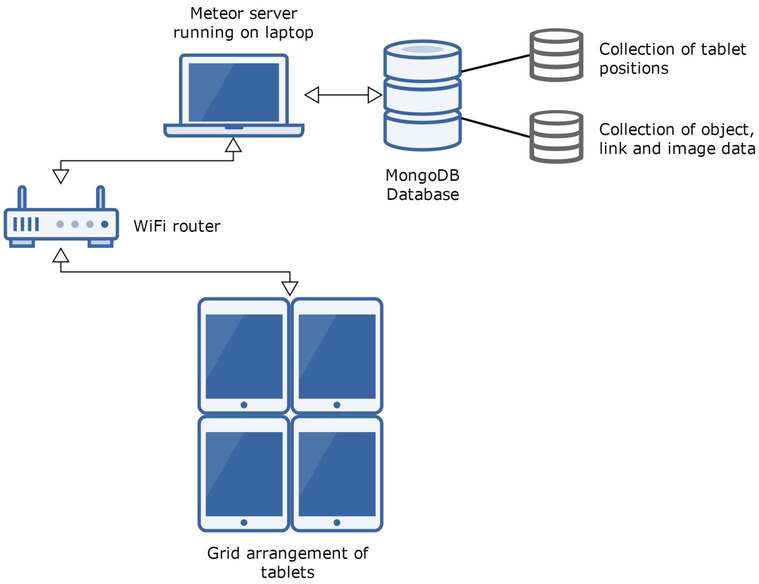

Figure 4.2: System diagram of tablets system showing client/server relationship

The software stack provided by Meteor uses a MongoDB[9] noSQL database and provides various functions to interact with this. It features templating which enables HTML to be automatically updated when data changes in the database, which makes it very easy to synchronise the tablets in this project. Meteor also allows client-side access to the MongoDB database, meaning that link, text and image data can be updated from each client when a change is made. It also offers latency compensation, which is important in this project to ensure that there is minimal latency when dragging an object from one tablet to another.

The application is structured around a core collection in the database, which stores id, name, location values, text content, background image, whether an object is active and data relating to links. When a change to these objects is made on any tablet the database is updated with these new values, which then updates all tablets (see Figure 4.2).

The interface of the application was implemented using Bootstrap and the Flat UI[10] theme, enabling the application to be more responsive and to adapt to the particular screen size of the device running it. This meant it was functional for the wide range of devices that it was required to work on. Creating the links between objects, which need to update as an object is dragged, was done using the jsPlumb[11] library. This uses svg images to draw the links and is then redrawn each time an object is moved or dragged. Multi-touch functionality was implemented using the Hammer.JS[12] library. Sound effects were also added to provide audio

[9] www.mongodb.org
[10] http://designmodo.github.io/Flat-UI/
[11] www.jsplumb.org/demo/flowchart/dom.html
[12] http://hammerjs.github.io/

cues when a link was made. Based on the cultural probes, fun was a major motivator for student engagement and these light-hearted audio cues aimed to appeal to this.

In addition to the application which synchronises data across tablets, the system also features a database which stores the positions of the tablets relative to each other. This functionality was largely provided by the HuddleLamp project as part of their tracking simulator, and allows the tablets to be arranged so that each displays the correct $1/4$ of the total canvas area.

4.2.0.1 Interaction

Users needed to be able to perform three important actions for the task: linking words and images, making text annotations and adding images. They also needed to be able to move all objects and undo or delete links, text and images.

To create links users tapped on one object to activate it, then tapped on another, which formed the link. When objects were activated this was synchronised across each of the four tablets, meaning that the system as a whole registered any change in active objects - allowing links within and between tablets. The linking action created a connection with an arrowhead pointing towards the most recently active object. A touch event was added to each link to enable users to delete links.

To enable the addition of text a text input box was added. This allowed users to type and then insert the text box onto the canvas, to be dragged to the appropriate location. Users could add images by dragging them onto the canvas from the photograph inventory. Both of these text and image tools were minimised at the bottom of the screen when not in use, ensuring they did not take up excess screen space. The text object opened an editing and deletion screen when users long-pressed it.

Overall the interaction was designed to be simple and to function in a way that would enable cross-device linking and dragging. Students had already demonstrated an understanding of standard GUI elements in the "design an app" task of the cultural probe, so it was felt that the use of common interactions and icons (such as the text tool minimised behind a text icon) would be intuitive without training. The focus of the interface was to provide a way to interact with content quickly and easily.

4.2.1 Limitations

One of the most common problems associated with swiping objects across tablets was the issue of accidentally pulling down the tablets' pull-down menu when swiping from the top. In the study this was solved by putting the iPads into guided access mode, which locked them into the application and prevented the pull-down menu from being displayed.

Similar to the requirement for a responsive application, the application also needed to adjust to the screen resolution, according to the pixels per inch (PPI) of the screen. This can be done by scaling the canvas and objects depending on the screen so that objects on different screens display at the same size regardless of device. This is important when different types of device are being used to create the networked tablet arrangement, as it means that when an object is dragged between screens it does not change size relative to the real world. For example when using iPad 3 (PPI 264 with a 2048 x 1536 resolution) and a iPad mini 2 (PPI 326 with a 2048 x 1536 resolution) the iPad mini displays the same amount of the canvas but on a physically smaller screen. The app displayed on the iPad mini can be scaled by $PPI(high)/PPI(low)$ to reduce the amount of the canvas displayed but keep the objects the same size as those on the physically bigger iPad. This can cause problems as some devices automatically scale the default pixel measure. An example of this would be that when using a iPad 2 (non-retina) and a iPad 3 no adjustment is necessary in spite of the differing PPI. It can also be difficult to get accurate resolution information from APIs available through web technology. This was implemented on this system but not tested with a wide variety of devices such as multiple Android tablets. In the evaluation all tablets used were the same model so it did not have any impact on the study.

Another issue encountered was that when typing on an iPad the on-screen keyboard pushes the content upwards. This causes links to not align correctly and can make it more difficult to pass objects between screens. In practise this was not observed as being a major problem, as users could easily close the keyboard, returning the content to the original position. However, future iterations of this system could potentially improve upon this by changing the default keyboard behaviour to one where the virtual keyboard overlays the content.

4.3 Content

In the development of the initial prototype the content of the system played a large part, as the activity determines many of the interface features that must be implemented.

The main requirement that the planned activity had to meet was to be effective at encouraging collaboration and discussion without a significant investment of time from participants. The entire study would need to be completed in under an hour, with participants completing three conditions and answering three questionnaires. The actual collaborative task was therefore required to take no longer than ten minutes.

For the collaborative activity, concept mapping was chosen as in previous work this has been reported to be an effective way to encourage discussion of ideas, especially when students are unfamiliar with the topic [56]. A paper by Son Do-Lehn et al used concept mapping to compare a table top interface with a traditional desktop computer [29], which provided some guidance. This activity asks participants to create links between concepts and annotate these links to show what they represent. For example, given the words "electricity" and "light bulb", one might create a link with the annotation, "electricity powers the light bulb". The application and content example can be seen in Figure 4.3.

The concepts were based on the New Zealand curriculum and teachers' suggestions of topics that would be relevant to the students. Concepts were also informed by the level of academic ability demonstrated in the cultural probes. The final solution running on the three conditions is shown in Figure 4.4.

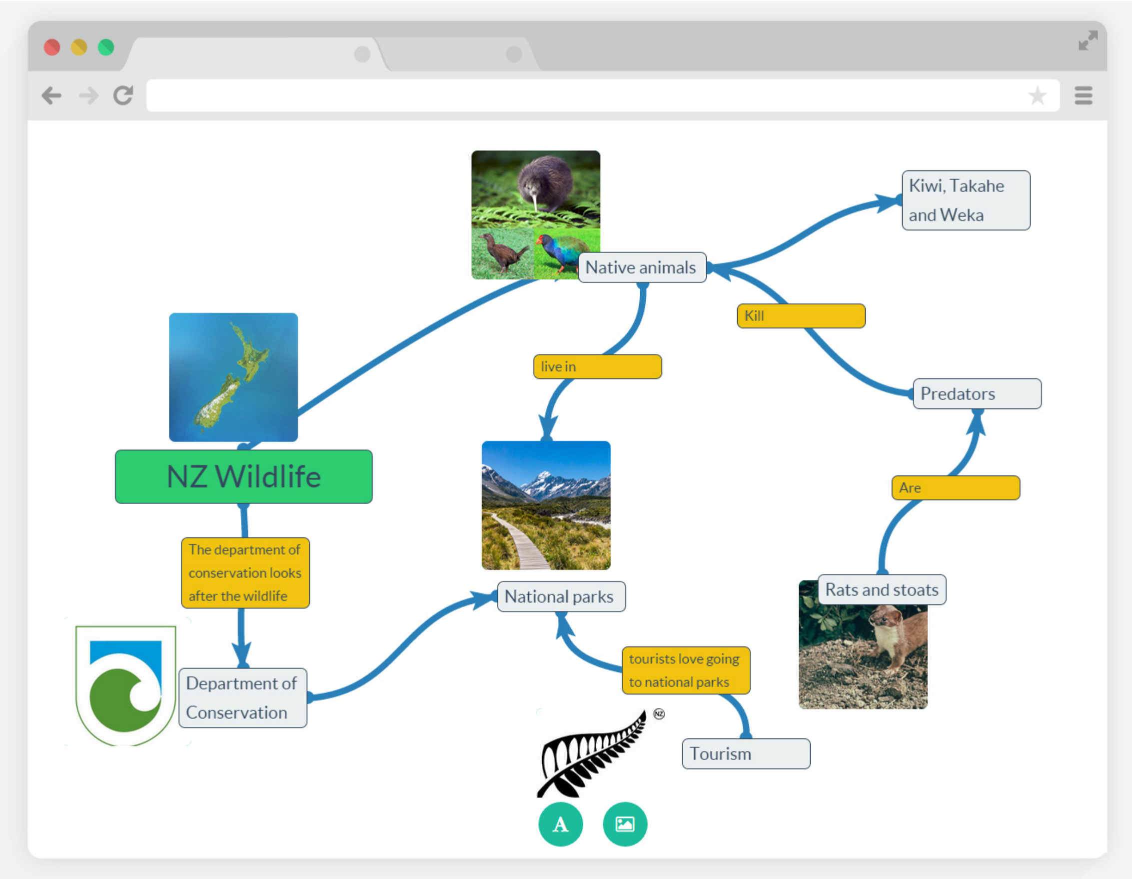

FIGURE 4.3: Concept map. Users can make links, text, and add images.

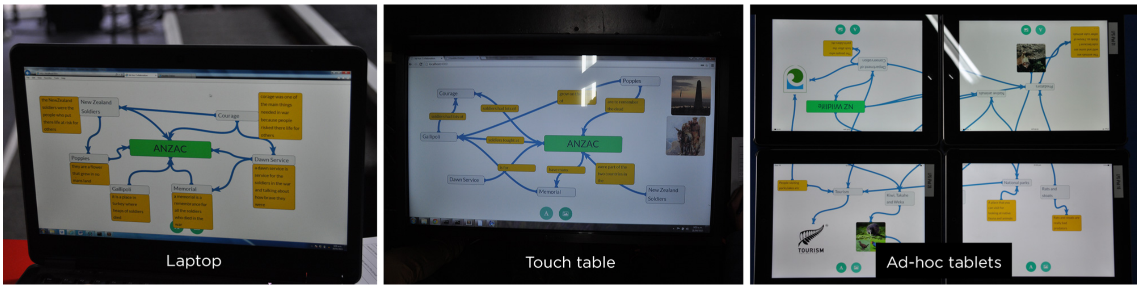

FIGURE 4.4: Completed concept maps for each condition

4.4 User testing

With a complete system developed a user testing session was run with other HIT Lab students to determine whether the system was robust enough for use in a user study. This pilot test highlighted the need to reduce latency in the tablets condition, which was a more noticeable problem with high numbers of links and text. Efficiency was improved significantly by altering the implementation of the jsPlumb and HuddleLamp software to reduce data transfer over the network and reduce the number of times links were redrawn when dragged.

4.5 Conclusion

This section has described the implementation of a collaborative activity software solution using new web technologies, namely the Meteor Javascript framework. Following its creation and testing across necessary devices a user study was designed to evaluate the collaboration on each condition. This study design is detailed in the following section.

Chapter 5

Study Design

In order to evaluate the suitability of the networked tablets arrangement for facilitating collaboration, a within-subject study was carried out with three different conditions: a laptop, a touch table and the networked tablets system.

5.1 Hypotheses

Two hypotheses were chosen for analysis in this study. Hypothesis one provides a benchmark against previous research for the touch table condition. Previous research has shown that groups working at touch tables engage in a higher quantity of collaboration than laptops/PCs [1][20][30]. In order to make comparisons between the new tablets system and the touch table condition it is necessary to determine whether the touch table system matches the results found in previous research, and is therefore a valid benchmark for collaborative work. Hypothesis two concerns the difference in collaboration between touch table and tablets. This provides evidence for or against the potential of this tablet system to facilitate collaboration.

H_A1: There will be a significant difference between the laptop and the touch table conditions in terms of quantity of collaboration.

H_01: There will be no significant difference between the laptop and the touch table conditions in terms of quantity of collaboration.

H_A2: There will be no significant difference between the tablets condition and the touch table condition in terms of quantity of collaboration.

H_02: There will be a significant difference between the tablets condition and the touch table condition in terms of quantity of collaboration.

5.2 Study design

Ethics for this study was granted by the Educational Research Human Ethics Committee at the University of Canterbury, reference number: 2015/02/ERHEC-LR. It was done with the permission and assistance of three classroom teachers from a local school. Students and parents signed consent forms and it was made clear that participation was voluntary. Those students who chose to participate were placed into groups of nine by their teacher and from these groups they then self-formed groups of three.

Students participated in the study in these groups of three. Each group completed three conditions: the laptop, touch table and the networked tablets system. On each of these conditions the users worked as a group to complete a concept mapping task, with a time limit of ten minutes. This task consisted of creating links between predefined, related words and images. The students were trained in the concept mapping task beforehand through a paper demonstration and instructed on the use of each technology. Groups used each condition for 30 seconds to familiarise themselves with controls before starting the task.

The study was run with three groups working on different conditions simultaneously. Groups were randomised to start on either the laptop, touch table or the tablets condition to reduce learning effects. The groups rotated after completing each condition. This rotation pattern is shown in Figure 5.1. On each new condition the content of the concept mapping activity was changed to reduce the bias that would have otherwise resulted from becoming familiar with the material. Each group was therefore creating a concept map based on the same concepts at the same time, but on a different technology condition. The concept map topics were also randomised across studies to minimise effects that may be caused by learning bias.

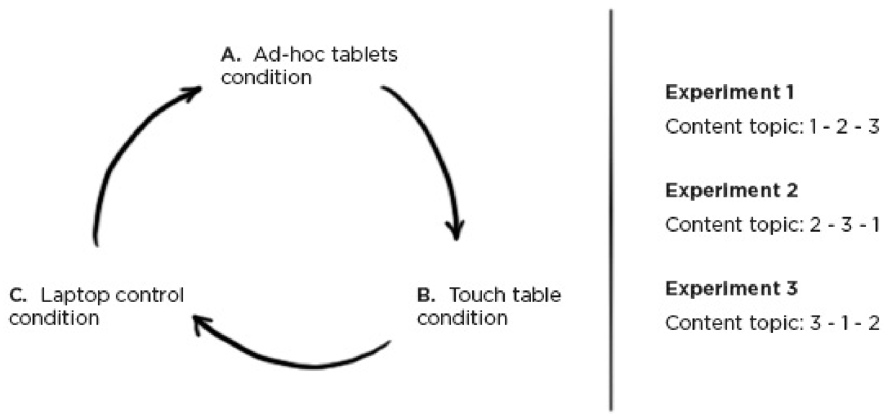

FIGURE 5.1: Rotation through conditions and content topics

Following the completion of each condition participants filled in a system usability form. Following the completion of all three tasks participants gave verbal qualitative feedback to the researcher as part of a short, five minute focus group.

5.2.1 Conditions

Differences between conditions

	Laptop	**Touch table**	**Tablets**
User space	Single user	Mixed user (multi-user dragging and linking, single user typing)	Multi-user (multi-user typing, dragging and linking)
Orientation	Vertical	Horizontal	Horizontal
Input	Keyboard and mouse	Touch	Touch
Screens	Single screen	Single screen	Multiple screens
Screen size (diagonal)	400mm	850mm	492mm
Resolution	1366 x 768	1920 x 1080	2048 x 1536

TABLE 5.1: Differences between conditions

The conditions in this study were chosen as being the likely technological options available to schools. A single, unmodified laptop was used rather than one laptop per student, due to the higher cost of laptops making one laptop per student less feasible. A multi-touch table was chosen over single touch as this is the more common commercial option for touch tables. The differences between conditions are outlined in Table 5.1.

5.2.2 Environment

The study was done on location in two decile 7 primary school classrooms over the course of three days, with approximately a week between each session. Doing the study on site made it easier for students to participate as they would only miss one hour of class time. It also minimised the effort required from teachers and school staff in planning lessons around the study. By locating the study at the school during normal school hours and running the study with nine users simultaneously, a benefit was also gained from creating an environment similar to a real classroom.

5.2.3 Materials

- Four iPads – owned by the host school
- A PQLabs multi-touch table

- Three laptops – one for the laptop condition, two to operate as local servers
- Three GoPros and tripods
- Three tables
- Nine chairs

The room was set up with stations placed at far corners to minimise inter-group discussion and recorded background noise. Each station had a GoPro on a tripod, a table, and chairs for the participants. The GoPro camera recorded the full activity for later analysis. The researcher was on hand to observe and answer any questions about the technology. The researcher did not provide assistance with task content nor behavioural management. Following the completion of each station the researcher distributed the usability surveys, took a photo of each groups' work and changed the content topic on each station.

5.2.4 Measures

5.2.4.1 System Usability Survey

To measure the perceived usability of each platform a system usability study (SUS) was done following each condition. This survey was modified from the original SUS survey outline by J. Brooke [57] in 1986, in order to make it easier to understand for the participants in this study. This was especially important for the younger students (eight to ten years old). The structure of the survey remained the same and the changes affected only the vocabulary used. This altered survey can be found in Appendix A. In addition to the SUS, two questions were added relating to how included the participants felt within the group. These were answered at the same time as the SUS.

5.2.4.2 Focus group feedback

In order to help triangulate qualitative findings, feedback from students was gathered as part of a focus group at the conclusion of each study. This focus group approach was based on work presented in "Research Methods in Human-Computer Interaction" by J. Lazar et al [58]. This work considers focus groups to be effective in gathering a broad range of opinions quickly, and suggests a group size of between eight and 12 people.

The specific questions students were asked were: "I'm going to ask you about what technology was your favourite, raise your hand to show your choice. Who liked the laptop the best? Who liked the table the best? Who liked the tablets the best?" The students were then asked why they thought their choice was the best, and why they didn't choose the other options.

5.2.4.3 Concept map output

In order to analyse whether the condition had an effect on the productivity of the group, the number of correct links, annotations and images were counted to provide a score for each concept map. The combined score was compared across conditions as well as the individual scores for each category of addition. This measure did not measure the quality of annotations, rather it just provided quantity of additions at the completion of the task.

Other more typical individual learning measures were not conducted in this study. It was expected that these would be unlikely to demonstrate any results due to the short task time and would place significant time requirements to conduct tests.

5.2.4.4 Coded video analysis

In order to quantify the assessment of collaboration down into quantifiable numbers, data was coded from video using a slightly modified version of the CLM framework, which is explained in this section (see Figure 5.2) outlined by R. Fleck et.al in "Actions speak loudly with words: unpacking collaboration around the table" [28]. As this analysis involved coding video data, efforts needed to be taken to reduce bias by the coder. Initially, in order to ensure the modified CLM framework provided unambiguous guidelines, the researcher and a third party completed analysis of videos separately and then compared their analyses to locate ambiguities in the framework. This provided iterative development of the framework for this specific context. This was done for four videos until a high level of agreement was reached. The researcher then completed the remaining analysis.

Mechanisms of Collaborative Discussion and Action	
Verbal Aspects	**Physical Aspects**
Making and accepting suggestions	
Presentations: - Making verbal suggestions and giving opinions Acceptances: - Listening to others' suggestions and opinions - Asking for clarification of verbal or physical suggestions	Presentations: - Use of gestures such as pointing at tabletop icons to ground talk - Demonstrating ideas by moving icons Acceptances: - Watching others' suggestions - Demonstrating others suggestions for clarification
Negotiating	
Making, listening to and responding to each other's suggestions as above	Watching and responding to each other's suggestions as above
Making alternative suggestions	Demonstrating alternatives - (Undoing)
Disagree *(below can all serve to protect own ideas)* Explanation of own ideas Justification of own actions Verbal blocking: telling others to 'stop' or 'put it back'	Undoing Physical blocking (to prevent undoing, and make time for verbal explanations or justifications) - Knocking hands out the way - Shielding an area of the table - Holding finger on icon

Mechanisms for Coordinating Collaborative Discussion and Action	
Maintaining joint attention and awareness	
(Mechanisms of collaborative discussion and action as above) Narrations: can inform others about your actions	(Mechanisms of collaborative discussion and action as above) Intrusions: physically disrupt others actions which can inform others about yours

FIGURE 5.2: CLM framework proposed by Fleck, R et al Red-coloured categories were not counted and blue-coloured categories were counted through overall time on task

Based on the CLM framework we performed the following analysis. Bullet points show the original CLM framework criteria, with a discussion of these points following.

- *Making suggestions: making suggestions, asking for clarification, demonstrating ideas physically.*

  Suggestions were only counted separately if they concerned a new idea. Repeating ideas was not counted unless it was part of an explicit request from another student for clarification. Spelling suggestions were not included. Gestures were only measured if they were used to suggest an idea, but not accompanied by a vocal suggestion.

  Demonstrating others' ideas physically was not counted as it was often difficult to determine whether the participant demonstrating the idea was doing it for clarification or simply adding the idea on behalf of the other person. Adding the idea on behalf of another person, while showing a helpful attitude, did not represent a new idea and as such was not counted.

- *Negotiating: Making alternative suggestions, demonstrating alternatives (changing others' work), disagreeing by arguing about an idea, disagreeing by asking others to "stop", physically blocking the user (eg. grabbing their hand).*

  In the case of asking each other to stop or physically blocking their hand, this was only counted as a negotiation if it was in response to defending an idea or addition and if the person had not verbally negotiated the same point. Listening to and watching others' suggestions was not counted as a negotiation, as this was more effectively measured with the time off-task measure.

- *Maintaining joint attention and awareness: Narrating your action, drawing attention to your action verbally or physically (eg. pointing)*

  Turn-taking verbalisations were not counted. The original CLM framework outlined above suggests listening to others' suggestions as part of the "making suggestions" category. However it was decided that determining what counts as listening and what does not was problematic, so the alternative method of timing all loss of focus or off-topic behaviour was chosen. Therefore in addition to this coding scheme we also measured:

- Time off-task or significantly off-topic for each member of the group.

  This provided a measure for the amount of time participants were looking away from the task and not responding or showing any engagement. It also measured time spent making off-topic suggestions and additions. This measure, by proxy, provided a measure of the time spent on-task, listening to and watching others' ideas.

5.2.5 Equality of participation

Equality of participation was also analysed, as equality of participation can be an indicator of high quality collaboration [8]. This measured the total equality by comparing the total contributions of each participant counted under the CLM framework. A Gini co-efficient was used to calculate this equality, as it has been shown to be an effective measure in previous papers [30][31][59]. As the analysis using the CLM framework counted both physical and verbal events, the equality measure did not provide separate measures for physical and verbal equality.

5.2.6 Qualitative video analysis

Following the CLM framework analysis the researcher conducted qualitative video analysis using a set of criteria based on dialogic talk guidelines outlined in "Towards Dialogic Teaching", a concept closely related to collaboration which promotes the use of talk and collaborative discussion for learning [60]. These criteria are as follows:

- *Collective: "Students address a learning task together as a group rather than in isolation"* [60].

  Specifically we looked for themes as to how the students divided the work (or didn't) and instances of students addressing questions to the group, using pronouns like 'we' and 'us'.

- *Reciprocal: "Students listen to each other, share ideas and consider alternative viewpoints"* [60].

  Specifically, the researcher looked for how many ideas were added to the concept map without discussion and how the students approached discussing suggestions already added to the map.

- *Supportive: "Students articulate their ideas freely, without fear of embarrassment about wrong answers. They help each other reach common understanding"* [60].

  Specifically, the researcher looked for behaviour where students encouraged other members of the group to engage with the task, discussed their ideas in a friendly manner and helped each other to articulate their ideas.

- *Cumulative: "Students build on their own and each others' ideas and chain them into coherent lines of thinking and enquiry"* [60].

  Specifically, the researcher looked for extended discussion around concepts or ideas that led to a different final answer than any initially suggested.

- *Conflict/Resolution: This category for qualitative analysis was addedin addition to the above four categories taken from the book by R. Alexander*[60].

  In this category the researcher looked for instances of argument and unproductive behaviour from group members and how this was affected by technology.

Chapter 6

Results

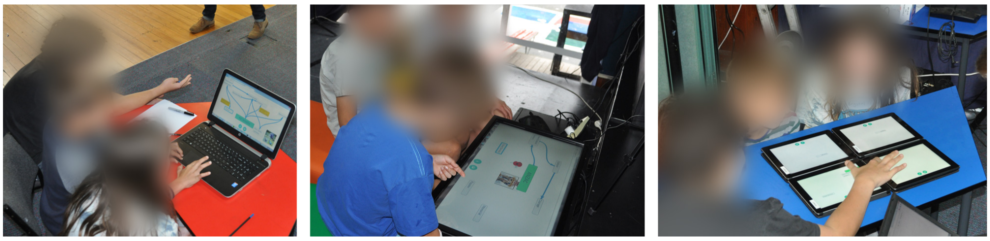

FIGURE 6.1: Photographs showing groups using each system

6.1 Demographics

Participants for this study were recruited from a local decile 7 primary school in Christchurch, New Zealand. In total the user group consisted of 54 students, with 29 females (54%) and 25 males (46%) between the ages of 8 and 12. The participants came from two classes within the school: the Year 5/6 class and the Year 7/8 class. All participants knew each other prior to the activity.

The participants in the study were divided into groups of three to perform each condition, with a total of 18 groups participating. Each group completed all three conditions. All participants had previously used iPads and laptops in their classroom and were very familiar with them. None had used a touch table or linked iPads in an ad-hoc arrangement before.

6.2 System Usability

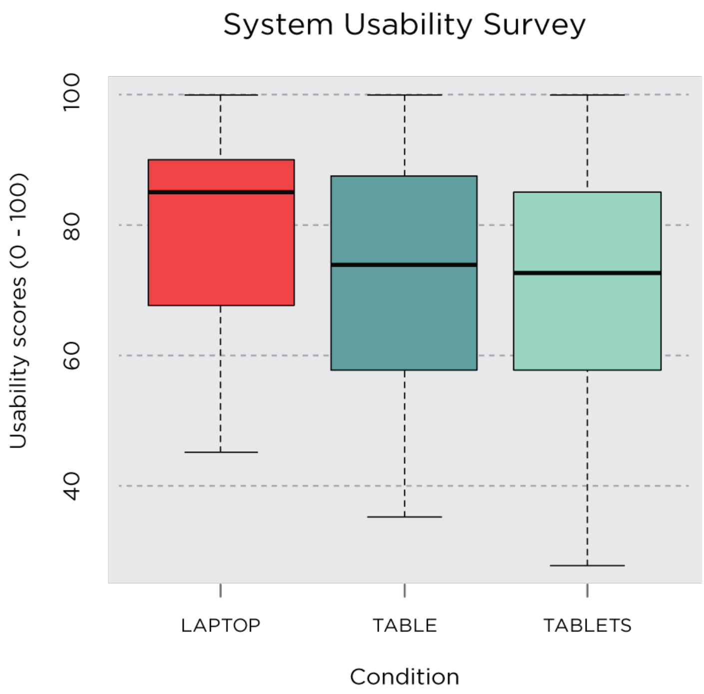

FIGURE 6.2: Boxplot showing SUS scores across conditions

The system usability survey measuring the perceived usability of each condition was completed by every student following each task. Higher scores represent higher perceived usability.

There was a statistically significant effect between the system usability scores using a Friedman Test ($X^2(2) = 10.34, p = 0.006$). Post-hoc analysis was done using Wilcoxon signed rank tests with a Bonferroni correction applied. With three comparisons being done the resulting significance level was set at ($p < 0.017$). There was no significant difference found between the table and the tablet scores ($Z = -0.483, p = 0.629$). A significant difference was found between the laptop and the table ($Z = -2.871, p = 0.004$), as well as between the laptop and tablets ($Z = -3.307, p = 0.001$), with the laptop having a higher SUS score in both cases (Figure 6.2).

Based on user feedback in the focus group it seems likely that this higher usability score in the laptop condition is due to users' familiarity with the laptop, and the keyboard, which enabled easier text input.

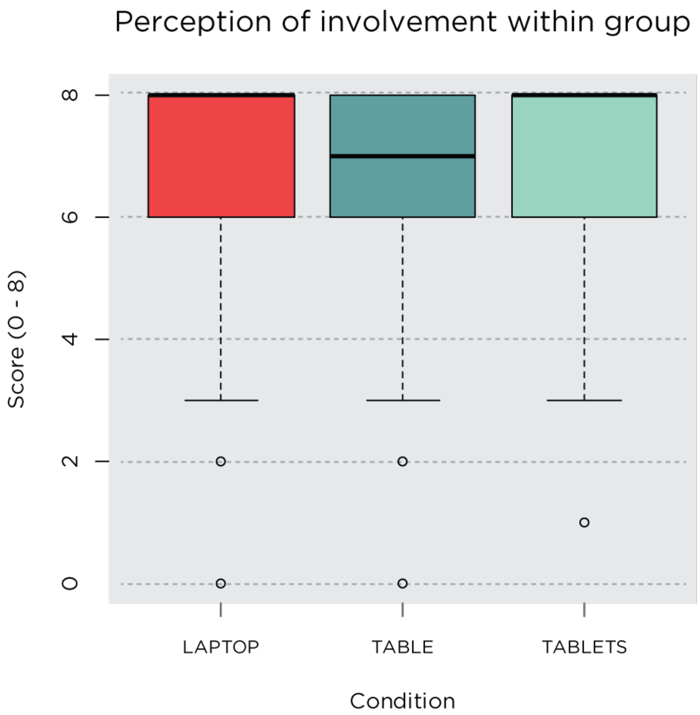

FIGURE 6.3: Boxplot showing total scores of questions relating to group involvement

Following the 10 question system usability survey students answered two questions regarding how they felt about their involvement in the group. These were: "I felt like I contributed well to the group.", "I felt included in the group". These questions were answered on a five point Likert scale ranging from strongly disagree to strongly agree. The above boxplot shows the combined result of these two questions. An analysis of this data with a Friedman test shows no significant difference between the conditions $(X^2(2) = 2.048, p = 0.359)$. The measure demonstrates a ceiling effect, probably meaning that the questions were worded in a way which caused participants to answer at the upper limit of the scale. This makes it impossible to determine if there was any effect due to condition.

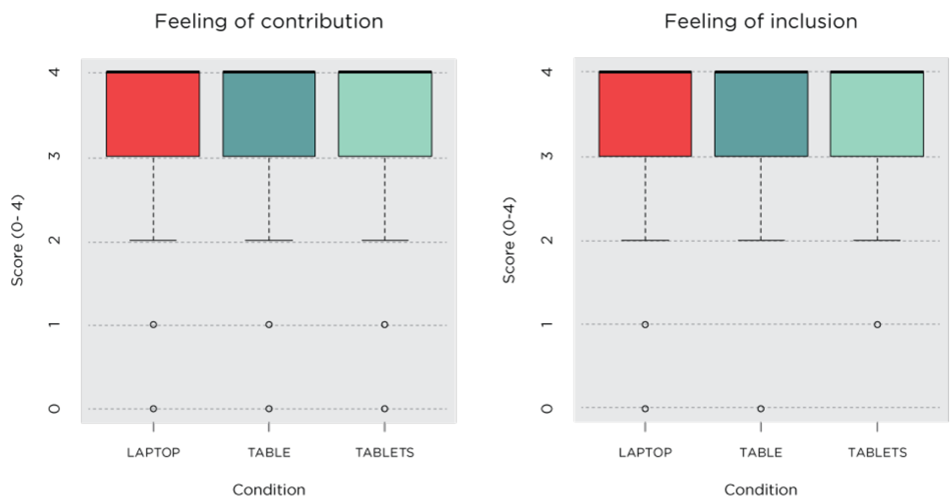

FIGURE 6.4: Boxplot showing total scores each question relating to group involvement

The plots of Figure 6.4 show the two questions concerning the feeling of involvement within the group individually. Feeling of contribution was analysed using a Friedman test which found no statistical significance between the conditions ($X^2(2) = 1.061, p = 0.588$). Feeling of inclusion was also analysed with a Friedman test which found no statistical significance ($X^2(2) = 0.911, p = 0.634$). The ceiling effect can be seen in each of these questions.

6.2.1 Post-study interview feedback

Following the completion of the three conditions, students were asked to provide feedback on the technology. Participants were asked to name their favourite technology (laptop, table or tablets) and following this they were asked why they chose their favourite.

The responses to these questions can be seen in Table 6.1. Although the students were asked to name one favourite, some named both the table and tablets. The touch table = tablets column shows the number of participants who voted for both conditions.

	Laptop	**Touch table**	**Tablets**	**Touch table = Tablets**
Responses on day	18	15	13	8
Late responses	*1*	*6*	*2*	*0*
Total	19	21	15	8

TABLE 6.1: Favourite technology platform feedback. Note that nine responses were lost so these participants had to be asked one month after the initial study.

Those who responded that they liked the laptop cited that it was more familiar, more accurate (clicking), the keyboard made typing easier, it was faster, performed as they expected it to and the flashing Alienware logo was 'cool'. Reasons given for not liking the laptop were that turns had to be taken and that it wasn't good for three people to use although it may have been for two.

> "We're just used to using the laptop, it was easier to click stuff."
>
> ***Group 16, Participant B***

> "The laptop was just the coolest. Alienware is a cool brand!"
>
> ***Group 6, Participant A***

Those who responded that they liked the table cited that it was new (novel), users could work at the same time, it was fast and it was big. Reasons cited for not liking it was that the interface did not always respond as expected and typing was difficult.

> "It [touch table] was big so you could all work at the same time."
>
> ***Group 14, Participant B***

Those who responded that they liked the tablets the best cited reasons such as: being able to work at the same time, didn't have to wait for others, it was easier to drag objects to the correct place. Reasons cited for disliking the tablets were: that the interface did not always respond as expected and that the bezels made links harder to understand and got in the way of dragging.

> "You could all work at the same time, you didn't have to wait for anyone."
>
> ***Group 8, Participant A***

6.2.2 Technology observations

6.2.2.1 Laptop

Overall the laptop was observed as having almost no technical issues or bugs. There were two occasions where images could no longer be dragged but this was quickly fixed by refreshing the page. All children were familiar with laptops and there were no observed instances of the hardware causing confusion.

6.2.2.2 Touch Table

Overall the participants had few issues in using the touch table and all groups quickly grasped how to use the touch screen to add links, text and images. The main issues observed with the table were caused by a flaw in the touch-sensitivity. The touch screen occasionally triggered two taps rather than one, resulting in typing being frustrating and difficult as typing errors were common. This also made creating links more difficult as objects were harder to select due to requiring a single tap. The problem with typing appeared to be the most distracting issue with the table as it slowed down text entry, which was often observed as being the catalyst for a loss of focus in other group members while they waited for an entry to be typed.

6.2.2.3 Tablets

Overall the tablets were used as the researcher intended them to be used. All groups were shown that it was possible to drag objects and make links across the tablets and all groups made use of this functionality. One common action that was observed, but not supported by the system, was participants trying to flick objects between tablets. Participants were observed to be aware that the tablets made up one big screen. The following quote illustrates this understanding following a demonstration of dragging between tablets:

> "Woah they're four different screen- oh they're a whole screen but." *(sic)*
>
> ***Group 16, Participant A***

The tablets were observed as having the most issues due to occasional network problems. These were corrected by the researcher as fast as possible, however this led to some distraction for participants and possibly resulted in slightly fewer additions being made. Another issue observed was that objects on the tablets sometimes became fixed in place and were not able to be dragged. This often proved distracting to participants, and was observed as being especially distracting to younger participants who spent more time attempting to drag these objects.

One area of concern when starting this project was that the tablets would be treated as personal and users would be unwilling to touch others' tablets due to not wanting to invade others' personal space. When observing the video footage this was observed to some degree in four of the groups, with students asking for others' permission to touch 'their' tablet or telling others to stop touching 'their' tablet.

6.3 Concept map output

In order to analyse whether the condition had an effect on the groups output, the number of correct links, annotations and images were counted to provide a score for each concept map.

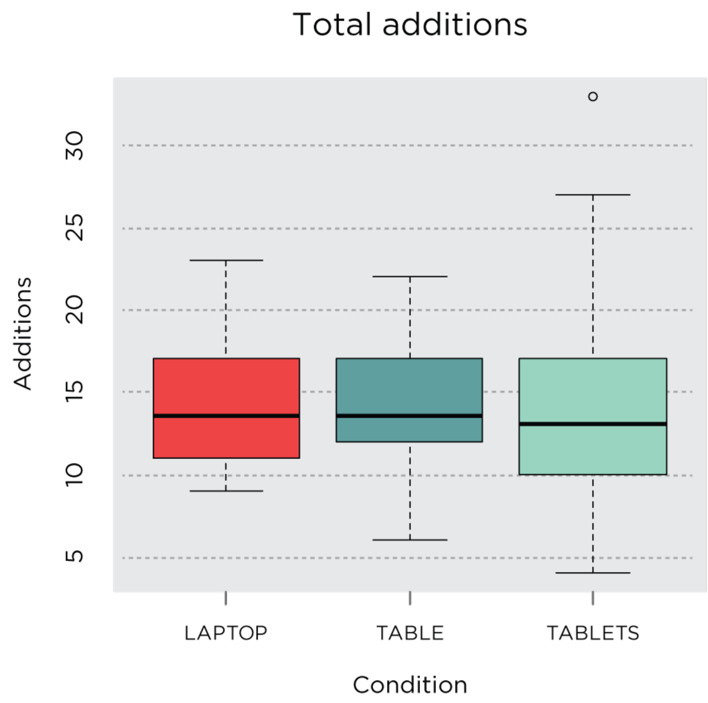

FIGURE 6.5: Boxplot showing total scores for each condition

The medians of the total concept map output measure (Figure 6.5) were 13.5, 13.5 and 13 for the laptop, touch table and tablets respectively. A Friedman test was used to analyse this difference, which was not found to be significant $(X^2(2) = 0.206, p = 0.902)$.

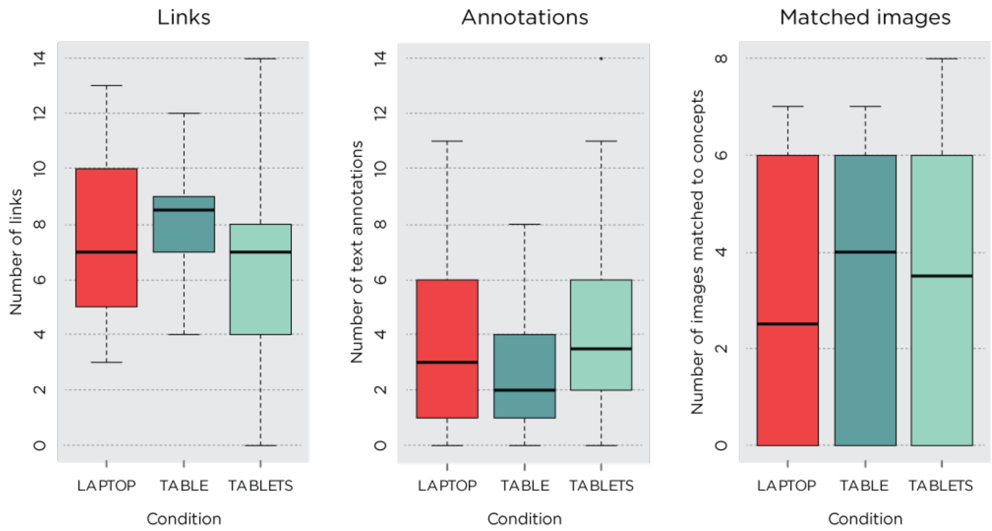

FIGURE 6.6: Boxplot showing breakdown of scoring for each condition

In order to provide more detailed insight the total additions were broken down into the three component parts: links between concepts, annotations of links, and images associated with concepts.

The medians of the links measure (Figure 6.6) were 7, 8.5 and 7 for the laptop, touch table and tablets respectively. A Friedman test was used to analyse this difference, which was not found to be significant $(X^2(2) = 0.903, p = 0.637)$.

The medians of the annotations measure (Figure 6.6) were 3, 2 and 3.5 for the laptop, touch table and tablets respectively. A Friedman test was used to analyse the differences in medians. The difference was found to be significant $(X^2(2) = 6.933, p = 0.031)$. A post-hoc analysis was done using a Wilcoxon signed-rank test with Bonferroni correction resulting in a significance level at $(p < 0.017)$. However, this did not find significance between any pairs: the touch table and laptop $(Z = -1.776, p = 0.076)$; the touch table and tablets $(Z = -1.970, p = 0.049)$; the laptop and tablets $(Z = -1.159, p = 0.247)$.

The medians of the images measure (Figure 6.6) were 2.5, 4 and 3.5 for the laptop, touch table and tablets respectively. A Friedman test was used to analyse the differences in medians. This was not found to be significant $(X^2(2) = -0.864, p = 0.649)$. A floor effect can be seen in this measure, which was likely due to some groups placing lower emphasis on adding images and then running out of time to add them.

6.4 CLM Framework

The CLM framework provides a set of behaviours which account for effective collaborative learning and was used to analyse the collaboration in this study. In this study it was iteratively developed further from the original specifications to ensure its applicability in this context and to develop rules specific to the content and application. Two coders analysed the data separately three times, comparing their answers following each analysis and using this to refine the framework. A fourth video was then randomly selected and analysed separately, with the analysis compared to assess inter-coder reliability. A linear-weighted Cohen's κ value of 0.620 was achieved. This is can be interpreted as 'good' agreement as suggested by Altman in 1991 [61]. The following results show the analysis of the different elements of the CLM framework.

By breaking down the analysis into its three component parts we can see the key differences between the three conditions. 'Suggestions' refers to the total number of verbal or physical suggestions made by groups in each condition. 'Negotiation' is the total number of events where participants negotiated or discussed a suggestion. 'Joint awareness' measures the total number occasions in which participants used a verbal or physical action to draw the groups' attention to a particular area or topic.

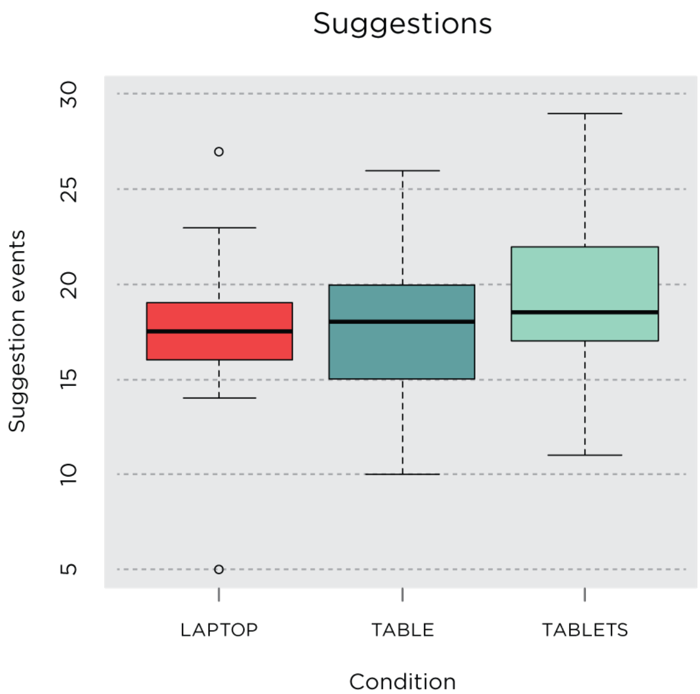

FIGURE 6.7: Boxplot showing number of suggestion events across conditions

Comparing the medians in the suggestion measure reveals small differences 17.50, 18.00 and 18.50 for the laptop, table and tablets conditions, however a Friedman test revealed that these were not significant $(X^2(2) = 4.388, p = 0.111)$ (see Figure 6.7).

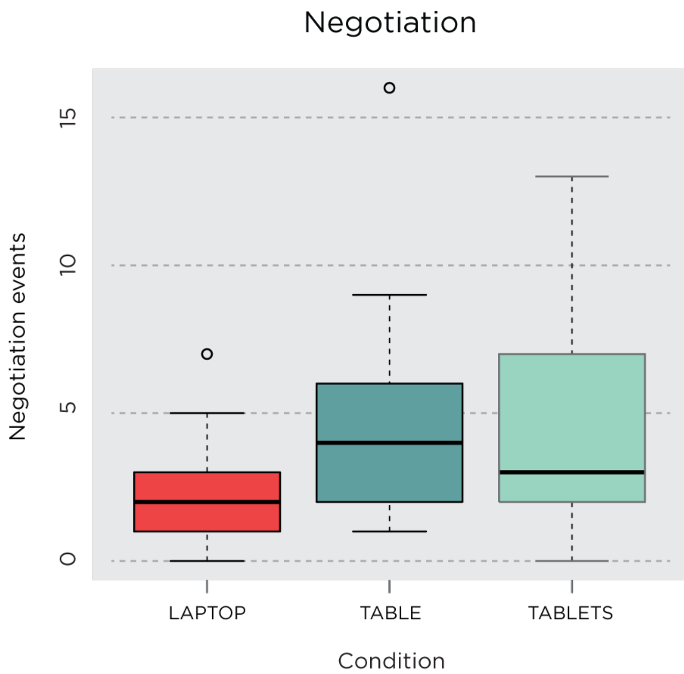

FIGURE 6.8: Boxplot showing number of negotiation events across conditions

The medians of the conditions in the negotiation measure were 2.00, 4.00, 3.00 for the laptop, table and tablets conditions, and a Friedman test revealed that these differences were significant $(X^2(2) = 6.303, p = 0.043)$ (see Figure 6.8). A post-hoc analysis was done using a Wilcoxon signed-rank test with Bonferroni correction resulting in a significance level at $(p < 0.017)$. This analysis showed no significance between the laptop and tablets conditions $(Z = -1.974, p = 0.048)$ and no significance between the table and tablets conditions $(Z = -0.238, p = 0.812)$. The difference between the laptop and table conditions was significant $(Z = -2.620, p = 0.009)$.

This significantly higher level of negotiation in the touch table condition as compared with the laptop demonstrates a higher quantity of collaborative behaviour, as negotiation is one of the mechanisms of collaboration as outlined in the CLM framework [28].

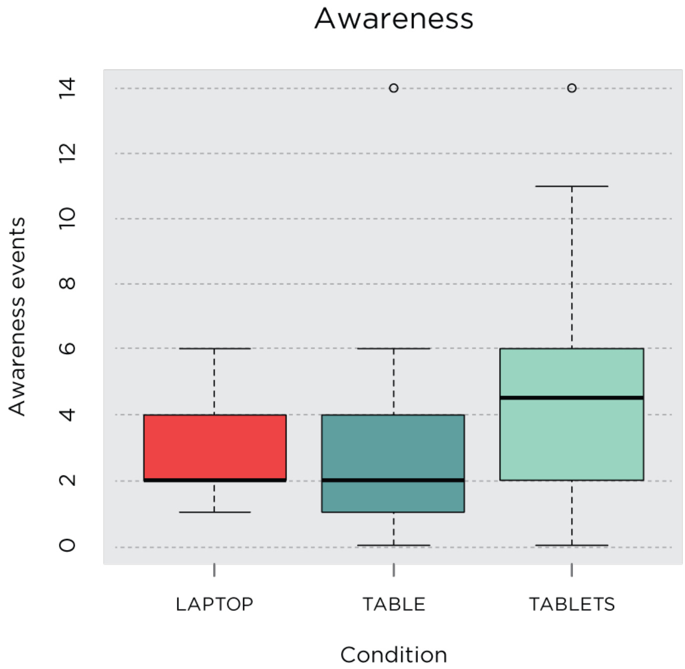

FIGURE 6.9: Boxplot showing number of group attention and awareness events across conditions

The medians of the conditions in the awareness measure were 2.00, 2.00, 4.50 for the laptop, table and tablets conditions. A Friedman test revealed that in the awareness measure there was a significant difference between the conditions ($X^2(2) = 8.129, p = 0.017$) (see Figure 6.9). A post-hoc analysis was done using a Wilcoxon signed-rank test with Bonferroni correction resulting in a significance level at ($p < 0.017$). This analysis showed no significance between the laptop and table condition ($Z = -0.229, p = 0.819$), and no significance between table and tablets conditions ($Z = -2.253, p = 0.024$). It did however show significance between the laptop and tablets condition ($Z = -2.479, p = 0.013$).

This higher level of awareness on the tablets condition seemed to be related to a lower implicit awareness than on the other conditions. On the laptop and touch table fewer input sources forced the group to collectively focus on a single point, which makes it less necessary to focus the group through vocal and physical actions.

6.5 Time off-task

Another measure was the time off task. This measures the amount of time in seconds that any member of the group was not paying attention or was making suggestions/additions that were significantly off-topic. Not paying attention was taken to be when a participant was clearly looking away from the screen, not vocalising any idea, and not obviously listening or thinking. This measure is important in the context of quantity and quality of collaboration. Listening and responding to others is part of the CLM framework, and on-task work is considered necessary for effective collaboration [28].

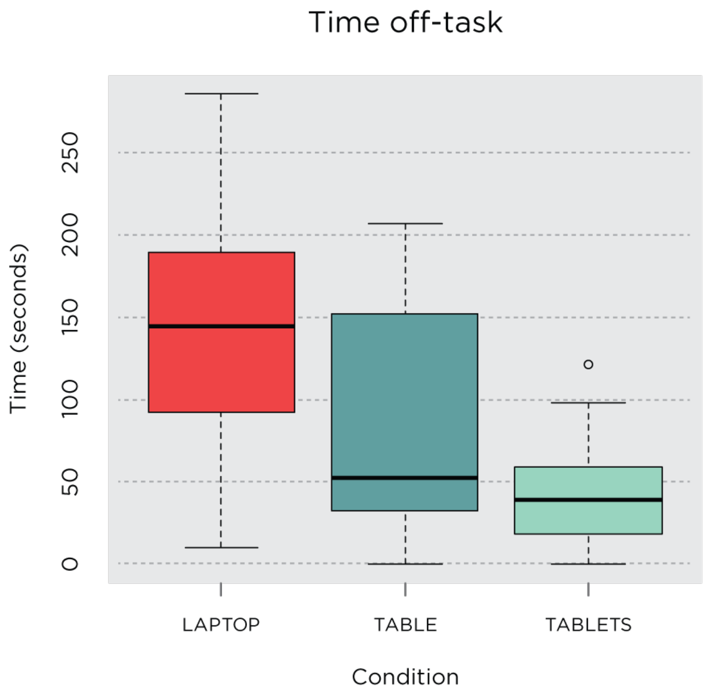

FIGURE 6.10: Boxplot showing total time off task for each condition

In order to test the data for normality a Shapiro-Wilks analysis was carried out on the data. While both the laptop and tablet condition data was considered normal - with $(p = 0.986)$ and $(p = 0.174)$ respectively – the table condition violated normality $(p = 0.017)$. In order to correct this a $log10$ transformation was applied to the dependent variable (time off topic). This transformation normalised the data and a follow up Shapiro-Wilks test was not significant. Analysing this transformed data using a Repeated Measures ANOVA found significance $(F = 7.532, p = 0.002)$. A post-hoc analysis with Bonferroni correction, meaning that the level required for significance was $(p = 0.05)$, found no significance between the table and tablet conditions $(p = 0.674)$. However between the laptop and tablet condition there was a mean difference of (90.661 ± 16.119) which was significant $(p = 0.001)$ and between the laptop and table a mean difference of (52.196 ± 19.742) which could be considered weakly significant at $(p = 0.072)$.

This result shows both the touch table and the tablets to have significantly higher engagement than the laptop. This is likely somewhat attributable to novelty (none of the participants had previously used a touch table, or a similar tablets system). However, this result does provide some evidence for the touch table and tablets being good platforms for collaborative work, as listening and responding to others ideas is an important contributor to both quantity and quality of collaboration [28][60].

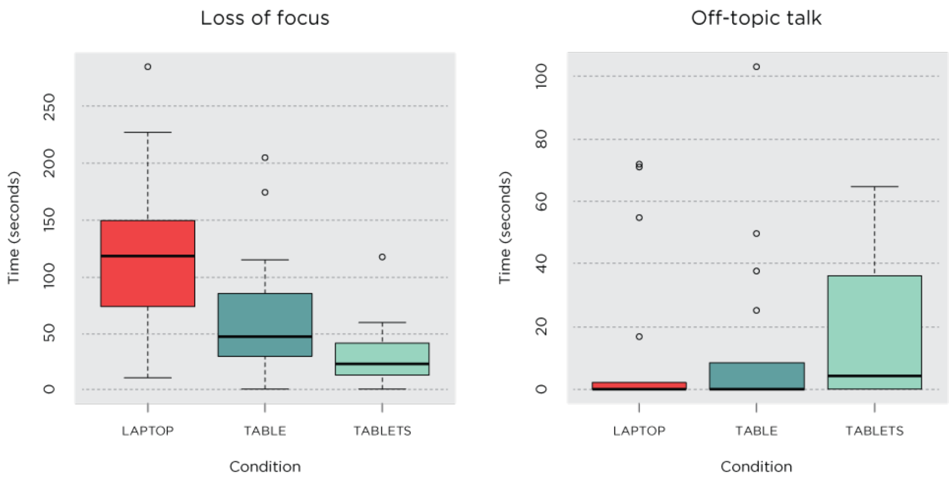

FIGURE 6.11: Boxplot showing breakdown of the two time off task measures - no focus and off-topic

The boxplots in Figure 6.11 give the breakdown of the two measures that make up the total off-task time measure. An analysis of the off-topic talk measure was conducted with a Friedman test (due to non-normal data distribution) and found no significant difference between the conditions in the off-topic talk $(X^2(2) = 2.085, p = 0.353)$. An analysis of the loss of focus measure was done with a Friedman test, due to non-normal data, and found that there was a significant effect between the conditions $(X^2(2) = -15.647, p = 0.0004)$. A post hoc analysis was performed using Wilcoxon signed rank tests with a Bonferroni correction applied resulting in a significance level set at $(p < 0.017)$. The post-hoc analysis showed that the medians of the laptop, table and tablets conditions were (118.000), (46.000) and (21.983) respectively. Between the laptop and tablets conditions there was a significant difference $(Z = -3.479, p = 0.001)$, between the laptop and table conditions there was what could be considered weak significance $(Z = -2.343, p = 0.019)$ and between the table and tablets there was also what could be considered weak significance $(Z = -2.343, p = 0.019)$.

6.6 Equality of participation

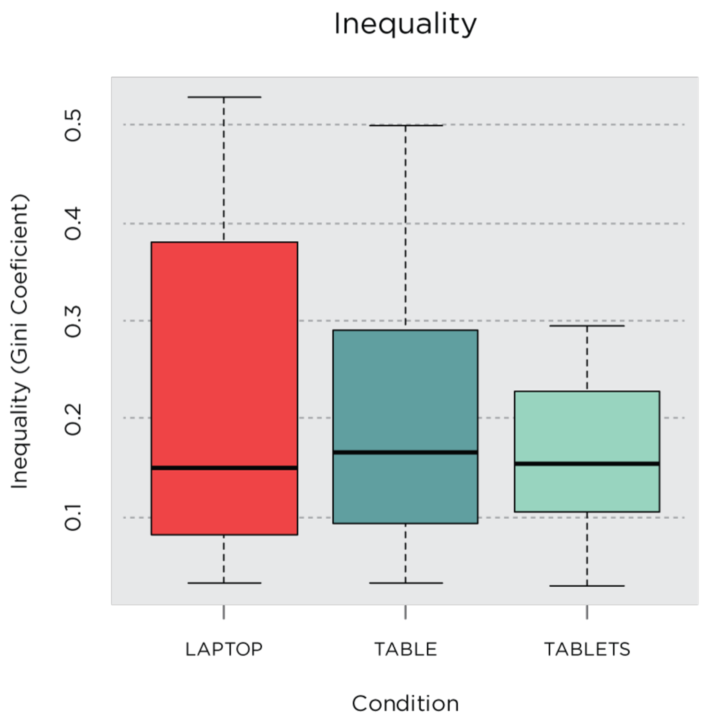

FIGURE 6.12: Boxplot showing inequality of collaborative events as a Gini co-efficient across conditions

Equality of participation measured the inequality between the total CLM events attributable to participants in each group. Equality of participation can be an indicator of high quality collaboration [8]. A Shapiro-Wilks test for normality was significant at $(p = 0.013)$ for the laptop condition, so a Friedman test was used to analyse the differences. A Friedman test revealed that there was no significant difference in equality between the conditions $(X^2(2) = 0.873, p = 0.646)$ (see Figure 6.12). This does not provide evidence in support of the quality of participation being difference across conditions.

6.7 Qualitative video analysis

In order to provide a richer interpretation of collected data the video recordings were re-watched in order to make qualitative observations of group and individual behaviour. This analysis used four elements of productive collaborative talk taken from Alexander's 2008 "Towards Dialogic Teaching – Rethinking classroom talk" [60] and one additional element (conflict/resolution). These behavioural elements were then further split into aspects of those elements. This framework can be seen in Table 6.2.

Elements of behaviour	**Aspects within the element**	**Definition**
Collective	Turn-taking	Explicit vocalisation of turns. Inputting ideas without group awareness.
	Dominated by one	Almost all ideas come from one person and they are in control of the technology/input for most of the task.
	Dominated by two	Two participants create almost all ideas and are in control of the technology for almost all of the task.
	Individual input	Members often type simultaneously without vocalising what they are adding.
	Collectivist	Members of group are all aware of what is being added and often focussed on the same concept. There is no turn taking or highly unequal control of technology/input.
Supportive	Encouraging others to engage	Members encourage others to take part who were not previously engaged.
	Praise post-input or suggestion	Members make positive vocal acceptance after another member makes input.
	Minor help	Members help each other with small problems like spelling or how to use the application.
Reciprocal	Vocalisation before input	Members vocalise their idea before adding it to the map.
	Listening and responding to others	Members show they are listening to others' ideas by responding in any way to suggestions.
	Discussion	Any disagreement, discussion, or alternative suggestion ending with an input.
Cumulative	Extended discussion	Extended (three or more vocalisations) discussion ending in an input.
	Inter-cognitive discussion	Extended discussion resulting in an input different to either original statements by individuals.
Conflict/Resolution	Unproductive disagreement	Active disagreement which does not lead to an input.
	Distraction	Member/s do or say things that are highly off-topic and serve to distract others.

TABLE 6.2: Five Elements of behaviour with their respective aspects

6.7.1 Collective

Elements of behaviour	Aspects within the element	Definition	Laptop	Touch table	Tablets
Collective	Turn-taking	Explicit vocalisation of turns. Inputting ideas without group awareness.	7	2	0
	Dominated by one	Almost all ideas come from one person and they are in control of the technology/input for most of the task.	1	1	0
	Dominated by two	Two participants create almost all ideas and are in control of the technology for almost all of the task.	3	1	2
	Individual input	Members often type simultaneously without vocalising what they are adding.	-	-	4
	Collectivist	Members of group are all aware of what is being added and often focused on the same concept. There is no turn taking or highly unequal control of technology/input.	5	14	12

Table 6.3: Collective element and aspects

The first element discussed is the Collective Aspect. The definition for collective was taken from R. Alexander (2008) [60] and was, "children address learning tasks together, whether as a group or as a class". The aspects of behaviour that the researcher looked for were how the groups divided their work and responsibility amongst the members, and how this affected the flow of ideas and inputs to the concept map.

Analysis of the video resulted in the definition of five behavioural aspects which make up the collective element of behaviour and are defined in Table 6.3. Groups were categorised into the aspect that best represented their group behaviour. This group count is shown in Table 6.3. The analysis enables insight into the behavioural elements exhibited by the groups when behaving in a collective manner. The sections below outline the behaviours and indicate their prevalence in the data.

6.7.1.1 Turn-taking

The condition that demonstrated turn-taking the most was the laptop. Seven of the groups on the laptop were classified as turn-taking and often demonstrated this behaviour in quite an explicit pattern, where one user dominated the device for a period of time before passing it on to the next person. The person whose turn it was often added a high number of text inputs, links and images, taking full control over additions to the concept map. The extract below illustrates this aspect with participant B talking to participant A regarding turn-taking on the laptop:

> B. "..It's your job."
> A. "Why?"
> B. "Because you do some, we do some, because we're taking turns"
>
> ***Group 15 (laptop)***

Groups in the touch table condition did demonstrate some turn-taking aspects, which was limited to inputting text without clear group awareness. No groups in the tablets condition demonstrated turn-taking, probably because there was more than one tablet each and therefore no need to take turns. This turn-taking behaviour did not appear to contribute to the collaborative nature of the learning process and did not seem to foster a collective group attitude. The turn-taking aspect of behaviour was often characterised by low engagement with the task from those in the group who did not have control over the technology.

6.7.1.2 Dominated by one

The 'dominated by one aspect' was defined as having almost all ideas come from one person who is in control of the technology/input for most of the task. This aspect was only demonstrated by one group, in two conditions. One participant with a dominant personality was the source of almost all the ideas and was the one who made almost all of the physical additions to the concept map. This group demonstrated this aspect on both the laptop and touch table conditions, but not on the tablets condition.

6.7.1.3 Dominated by two

'Dominated by two' was characterised by two participants creating almost all additions and controlling the technology and input for almost the entire task. This was demonstrated in all conditions: three groups in the laptop condition, one with the touch table and two with the tablets. However the researcher observed that on the tablets condition this aspect was less pronounced in the two cases where it did occur, likely due to the multiple inputs reducing the potential for blocking behaviour from the dominating participants. The data suggests that this aspect often caused the third person to lose interest and became disengaged.

6.7.1.4 Individual input

'Individual input' was an aspect where individuals in the group often typed and input text without vocalisation or explicit awareness from others. Individual input was an aspect that was only observed in the tablets condition as the tablets were the only technology with multiple inputs which facilitated the behaviour. In this aspect it was common for text to be typed/input simultaneously, however this may have led to less collective group behaviour through a lower awareness of what the group was doing as a whole. While the addition of text was often an individualistic activity it was still common to see groups work collectively on group concepts, create links (within and across tablets), and add images. The extract below illustrates this aspect, with participant A inputting text without prior vocalisation, paired with a weak group attention utterance, to make the others in the group more aware of what has been added:

> “ [Participant A, B and C are all typing]
> A. "What should I say? [no responses given]" [types and then inputs text]
> A. "Rats and stoats… [the input topic]"
> B. [looks at participant A's input] "Ok."
> ”
>
> ***Group 11 (tablets)***

6.7.1.5 Collectivist

Collectivist behaviour was characterised by groups commonly having joint focus and all members contributing to the task. This was the aspect most commonly observed, with five groups in the laptop condition, 14 in the touch table and 12 in the tablets. Four of the groups that demonstrated collectivist aspects on the laptop condition also demonstrated this behavioural aspect on both other conditions. Groups showing collectivist behaviour tended to involve members of the group simultaneously, especially in the touch table and tablets conditions (shown in Figure 6.13). In the touch table and tablets conditions participants could more easily access the technology and therefore make physical changes at the same time as others in the group. At the start of the task in the touch table and tablets conditions almost all groups (including those that overall were characterised as turn-taking or individual input) added links and moved concepts to appropriate place simultaneously. Collectivist groups were also commonly observed to have a higher number of vocal contributes to the group (rather than individuals) than other aspects. This is evidenced through the quotes below. Participant B and participant C addressing group:

> “ B. "We could move this one down here [moves word]"
> C. "Yeaaa, and then this one up here [moves word]"

Group 14 (table)

Participant A discussing with participant C what to connect directly to the central concept (NZ Wildlife):

> C. "Kiwi, Takahe and Waka..Wake..Weka."*(sic)*
> B. [makes link between "NZ Wildlife" and "Kiwi, Takahe, Weka"]
> A. "Nooo, don't go straight to that or you'll ruin the love heart."

Group 1 (tablets)

FIGURE 6.13: Screen captures showing collective behaviour on all conditions

6.7.1.6 Summary

The collective element is a core behavioural element in creating effective collaboration. It represents how the group structures itself and distributes work amongst itself. The most apparent differences observed between conditions was the common occurrence of turn-taking on the laptop, which was less common on the other two conditions. The groups using the tablets also occasionally displayed a unique behaviour of individual input, where two or more individuals in the group typed at the same time, losing awareness of what others were typing.

6.7.2 Supportive

Elements of behaviour	Aspects within the element	Definition	Laptop	Touch table	Tablets
Supportive	Encouraging others to engage	Members encourage others to take part who were not previously engaged.	17	15	16
	Praise post-input or suggestion	Members make positive vocal acceptance after another member makes input.	16	16	16
	Minor help	Members help each other with small problems like spelling or how to use the application	17	17	17

TABLE 6.4: Supportive element and aspects

The supportive element of behaviour was originally defined as: "Children articulate their ideas freely, without fear of embarrassment over wrong answers. They help each other reach common understanding". In the analysis three aspects were defined that were observed as being the most common ways in which participants created a supportive atmosphere within the group.

These three aspects are defined in Table 6.4. For each aspect the count of groups that displayed this behaviour is shown. Encouraging others to engage and minor help were dependent on whether a group member was disengaged or struggling with technology/spelling. Because of this groups were counted so long as they demonstrated this, even in a minor way. For example: encouraging the group to engage through a joint awareness statement or providing minor help to another group member even if the issue was quickly resolved by the original user.

Supportive behaviour was widely observed across all conditions, and overall the groups worked well together with little to suggest that participants were unwilling to make contributions due to fear of embarrassment. The supportive climate of most groups appeared to be attributable mostly to their prior relationships with each other and a desire to be fair.

6.7.2.1 Encouraging others to engage

Encouraging others to engage was defined as being when a participant vocally encouraged others to engage with the task when they had previously not been engaged with it. Encouraging others to engage could be said to be involving them more in the group decision-making process or, in some cases, could be indicative of turn-taking which would imply a link with the collective behaviour element. However, because it was observed across a range of the collective aspects, it was defined as being part of the supportive aspect.

Encouraging others to engage was observed across all conditions. It was also observed that the number of vocalisations of this aspect was quite consistent across conditions. The following quote illustrates this aspect, as participant A addresses the group, and then engages specifically with participant C:

> A. "So, what word could we write?"
> B. "The port is located in Lyttelton"
> A. "Is that good? Do you like that [participant C]?"
> C. "Yea"
>
> ***Group 3 (tablets)***

There were also occasions observed where suggestions were discouraged. These were observed on both the laptop and touch table conditions. These instances were not supportive and were observed as being related to turn-taking behaviour. They occurred most often when a participant tried to make an addition to the concept map when it was not their turn which would block the current user's actions if not stopped. This is shown in the following excerpt with participant A asking to add an image while participant B is using the laptop:

> A. "Ok, now go back to photos, can I do something [participant B]?" [reaching for laptop]
> B. "No. [brushes away hand]"
>
> [30 sec later participant B opens the photo panel, giving participant A an opportunity to make her suggestion]
>
> ***Group 7 (laptop)***

6.7.2.2 Praise post–input

Praise post-input was defined as giving praise to another participant in the group after they made a vocal suggestion or physical addition to the concept map. Praise, like encouraging others, was observed on all platforms with no observed differences in the number of occurrences across technology. Giving praise was observed to be motivated by personality and social structure within the group. An example of the aspect is given below. Participant B draws attention to his addition and participant A praises it:

> B. "Christchurch is the ship's gateway.."
> A. "Yep. That's good."
>
> ***Group 8 (laptop)***

6.7.2.3 Minor help

This aspect was defined as occurring when a member gave another member help or advice with something not specifically related to the task, for example: spelling, grammar or help with how to use the software. Minor help was also observed in all conditions and participants were observed to generally be friendly and happy to offer help to others in their group. It was, however, more commonly observed in the touch table and tablets conditions due to a higher number of difficulties in interacting in these conditions which gave the students more opportunities to offer help related to the technology. The following excerpt provides an example of this minor help as participant B helps participant A with spelling of "dolphin".

> “ B. [typing]
> A. "It’s dol-P-H-in"
> B. "P what?" [participant A types to complete the word dolphin] ”
>
> ***Group 17 (table)***

6.7.2.4 Summary

The supportive element represents how a group works together to create an environment which is positive and supports others ideas. In this study it was observed that most groups were effective in creating a supportive environment with few situations demonstrating unsupportive behaviour being observed.

6.7.3 Reciprocal

Elements of behaviour	Aspects within the element	Definition	Laptop	Touch table	Tablets
Reciprocal	Vocalisation before text input	Members vocalise their idea before adding it to the map.	13	18	15
	Listening and responding to others	Members show they are listening to others ideas by responding in any way to suggestions.	16	18	18
	Discussion	Any disagreement, discussion, or alternative suggestion ending with an input	5	12	12

Table 6.5: Reciprocal element and aspects

A reciprocal environment provides a foundation on which more in-depth discussion can occur. This section breaks down the reciprocal element into smaller aspects and analyses differences across conditions.

The reciprocal element of behaviour was originally defined as: "Children listen to each other, share ideas and consider alternative viewpoints" [60]. In our analysis we defined four aspects that we observed as being common ways in which a reciprocal attitude was manifested (see Table 6.5). The groups were counted for each aspect if they displayed these behaviours. "Vocalisation before text input" required the majority of inputs to be preceded by a vocalisation. "Listening to and responding to others" also required that the majority of vocalisations received responses. Groups counted under "Discussion" needed to display the behaviour on at least three occasions.

6.7.3.1 Vocalisation before text input

This aspect considered the number of occasions where an annotation idea was vocalised to the group before being added to the concept map. Annotation was looked at specifically as it was observed to be common across conditions to add links and images without vocalisation, which was likely due to the high visibility and therefore implicit awareness these actions have. This differs from the joint awareness measure in CLM framework which did not require the utterance to occur before the input, and indeed it was commonly observed behaviour on the tablets to narrate an action while doing it, or tell the group after making the addition. This was an important aspect to consider as it was observed that a vocalised idea almost always resulted in a response from another group member and also led to discussion more often than non-vocalised additions. It was less common for text inputs that had been added without vocalisation to be discussed and edited.

The laptop condition was observed as having a comparatively low (13) amount of vocalisation before input. It was observed that in groups that displayed turn-taking behaviour the vocalisation of ideas was lower, as participants whose turn it was had a higher likelihood of adding non-vocalised ideas. The touch table and tablets conditions were observed as having high(18) and medium(15) vocalisations before input respectively. The tablets appeared to have lower vocalisation particularly in the groups that would be classed as "individual input" in the collective element. In these cases participants tended to simply add text additions without proposing them to the group or drawing attention to them. The quote below demonstrates a participant vocalising an idea, in this case before hitting insert, but after typing. It shows participant C responding to the idea as a direct response to her vocalisation.

> “ A. "That works right? Lyttelton port with settlers?"
> C. "Yeaa, yep." *(sic)*
> A. [taps insert to add the text] ”
>
> ***Group 9 (table)***

Interestingly the touch table had the highest level of vocalisation, this is in spite of previous observations that there was usually high implicit awareness of what was being written in this condition. It appeared that because the action blocked other users from typing, users were more likely to narrate their typing or explicitly tell the other members what they were doing, as a qualifier for their action.

6.7.3.2 Listening to, and responding to others

Listening to, and responding to others looked at how often members responded to others' suggestions in any way. As was previously observed in the vocalisation before input aspect, having an idea vocalised before being added was observed to increase the likelihood of response from others. Almost all vocal ideas, vocalisations to draw attention or utterances to organise the group (e.g. "guys let's add some images") were met with some vocal response regardless of condition. However, as these vocalisations were observed to be more common in the touch table and tablets conditions it was observed that the highest rate of listening and responding to others was on the touch table and tablets. These responses were less common on the laptop.

On all conditions participants were occasionally observed responding to an addition made physically but not vocalised. This only occurred when there was joint focus from both the original participant adding the idea and the participant responding. As such this was observed at a slightly higher rate on the touch table and tablets due to the higher engagement and focus on these conditions shown in our previous analysis of engagement. The following excerpt from the data demonstrates a response to a non-vocalised addition, in which participant A responds to a typo in an addition made by participant B.

> “ B. [adds text input and drags it to another screen]
> A. "Goes..what?"
> B. "Haha, that's autocorrect" [deletes text] ”
>
> ***Group 10 (tablets)***

6.7.3.3 Discussion

Discussion was defined as being when a participant responded to another's suggestion by either disagreeing or offering an alternative idea, and required that this discussion lead to an input as a way to measure the productiveness of this discussion. This aspect also counted disagreement or alternative suggestions which were not vocalised but demonstrated by physically undoing or changing an existing addition. For a group to be counted in this aspect it was required that discussion be demonstrated three or more times. The following quotation demonstrates this aspect as participant A makes a suggestion and participant B responds with an alternative suggestion:

> “ A. "Kiwi, Takahe, Weka help the tourism industry."
> B. "How about NZ Wildlife goes to tourism industry?" ”
>
> ***Group 8 (tablets)***

The laptop condition was observed to have a low (5 groups) level of discussion. The tablets condition and the touch table condition were observed to have a higher (12 groups) level of discussion. This discussion was most commonly vocal discussion, with an idea being suggested and then being discussed by other members of the group vocally.

The touch table condition also had a high rate of non-vocalised text inputs being vetted and discussed by the group prior to adding them to the concept map. This was likely due to a combination of factors such as high engagement and a single input promoting single group focus, which meant that participants were more likely to read the text before it was added. Both the laptop and the tablets conditions had a low rate of non-vocalised inputs being discussed prior to addition to the map.

Physically undoing or editing and addition was observed commonly in the context of changing links or images; however it was uncommon to edit text inputs after their addition across all conditions. Links were often observed to be edited physically on the touch table and tablets conditions and deleting and changing these links was a common way in which the links were discussed. This behaviour was also observed on the laptop condition, however it was more common on this condition to vocally suggest a link before creating it and less common for others in the group to physically edit it after its addition. As demonstrated in the following quote where participant A makes a vocal suggestion and participant C adds it.

> “ A. "…And then NZ Soldiers to courage"
> C. [Participant C adds link between NZ soldiers and courage] ”
>
> ***Group 12 (laptop)***

6.7.3.4 Summary

Analysis of reciprocal behaviour reveals that groups using the laptop were the least likely to demonstrate reciprocal behaviour in all aspects. Groups on the touch table demonstrated reciprocal behaviour most often, with the tablets similar in most regards.

6.7.4 Cumulative

Elements of behaviour	**Aspects within the element**	**Definition**	**Laptop**	**Touch table**	**Tablets**
Cumulative	Extended discussion	Extended (three or more vocalisations) discussion ending in an input	4	10	8
	Inter-cognitive discussion	Extended discussion resulting in an input different to either original statements by individuals	0	1	0

TABLE 6.6: Cumulative element and aspects

Cumulative behaviour is a core part of effective collaborative work and effective discussion, improving test scores [62] and engaging participants in critical thinking.

The cumulative element was defined as "Children build on their own and each other's ideas and chain them into coherent lines of thinking and enquiry" [60]. Two aspects that represented this were defined (see Table 6.6), and are analysed below. Cumulative development of ideas was closely related to the level of negotiation, especially verbal negotiation as this tended to involve more members of the group and led to more cumulative in-depth discussion. Groups that demonstrated these aspects once or more were counted. This count is given in Table 6.6.

6.7.4.1 Extended discussion

Extended discussion was defined as a discussion in which there are more than three responses in total, these discussions were more than just a disagreement or correction but required a back and forth exchange between at least two group members. This aspect also required that an input be made following the discussion, as a measure for the productivity of the discussion. The total count of groups in which extended discussion was observed is given in 6.6. The touch table provided the most observed extended discussion, followed by the tablet and then laptop. The following excerpt illustrates extended discussion occurring on the tablets condition. The quote shows how participant A draws group awareness to the addition which sparks discussion.

> “ A. [inserts text] "Guys look I put tunnel there, OK? Tunnel is connected to Lyttelton.
>
> B. "No. [It should connect] to Christchurch, which is connected to Gateway"
>
> A. "Why don't we just connect tunnel to sea?"
>
> B. "No, they need to be connected [pointing to gateway and tunnel] cos the gateway is the tunnel"
>
> A. [makes several links] ”
>
> ***Group 5 (tablets)***

In the touch table and tablets conditions the higher engagement and more equal access to the screen/s was observed to increase extended discussion. This was especially true of minor cumulative behaviours such as moving others' suggestions and image additions to the correct location. However due to lower vocalisation of suggestions afforded by the multiple inputs there was a lower amount of observed cumulative behaviour than the touch table condition.

6.7.4.2 Inter-cognitive discussion

Inter-cognitive discussion was characterised by an extended discussion with a following input that was different to either of the participants' original suggestions. This was not a commonly observed aspect in any condition, perhaps due to the short time given to complete each task which may have tended to encourage groups to make additions without long, in-depth discussion. The following quote shows inter-cognitive discussion, as an entirely new suggestion is made (Bridle Path is in Christchurch) by building on the combined group knowledge.

> C. [typing suggestion about Bridle Path (not vocalised)]
> B. "No say the Bridle Path is in Lyttelton"
> C. "No cos it's in Heatchcote and Lyttelton"
> A. "It's in between"
> B. "Well then write: Bridle Path is in Christchurch"
>
> ***Group 4 (table)***

As inter-cognitive discussion occurred at low rates there was not sufficient data for the researcher to clearly observe differences between the conditions. However, the one observed occurrence followed a series of three discussions based around the same topic during the task. It seems likely that extended discussions would be something of a precursor to cumulative discussion, as this gives participants time to reevaluate original responses and arrive at a new idea.

6.7.4.3 Summary

Cumulative behaviour was not commonly observed in any condition, likely due to the short nature of the task. Where it was observed it seemed to correlate to high levels of vocalisation and discussion, as was observed on the touch table and tablets.

6.7.5 Conflict/Resolution

Elements of behaviour	Aspects within the element	Definition	Laptop	Touch table	Tablets
Conflict/Resolution	Unproductive disagreement	Active disagreement which does not lead to an input	1	2	1
	Distraction	Member/s do or say things that are highly off-topic and serve to distract others	3	3	4

TABLE 6.7: Conflict/Resolution element and aspects

While most groups worked well together, there were occasions where minor conflicts arose, as well as some cases where participants acted in a distracting way. These conflicts were defined as being when a member of the group actively disagreed or acted in a distracting way and that this behaviour did not lead to an input (see Table 6.7). The way these conflicts arose and the impact of distracting behaviour was observed as varying between conditions. Groups were counted for each aspect dependent on if they demonstrated the behaviour once or more.

6.7.5.1 Unproductive disagreement

Unproductive disagreement was defined as being a disagreement, which did not produce an input as a result. This unproductive disagreement aspect was observed as occurring on all conditions. The following excerpt demonstrated this unproductive disagreement:

> A. "...And link the port to the bridle path"
> B. "Nooo."
> C. [Participant C focuses on another area of the map and makes a separate link]
>
> ***Group 2 (laptop)***

6.7.5.2 Distraction

Distraction was defined as any behaviour that intentionally distracted other group members through vocalising or adding unrelated ideas. In total there were five groups which had at least one member who caused distraction and was often off-topic in at least one condition. This was spread across all conditions. The cause of this behaviour was not observed to be related to the technology, however the way it was dealt with, and its impact on the group, did differ across conditions.

Distracting behaviour from one member of the group was commonly observed to be dealt with by other group members physically blocking them from input devices and pushing them to focus and stay on track. This was observed to be consistent across conditions. However when two members of the group lost focus the impact was observed to be greater. In the four groups where this occurred the impact of their actions were observed to have a larger impact on the laptop and touch table conditions.

The laptop and touch table conditions were observed to be more easily dominated by members of the group who had become distracted or lost interest in making serious contributions. By having a single input - or in the case of the touch table, a single text input and an ability to prevent others from making links and images by tapping to cancel their actions – these participants blocked almost all productive work by the other member who was making some effort to stay on track. The following quote illustrates this distracting aspect, as participant A distracts participant B and prevents her from making an addition.

> “ B. "No, no, it doesn’t matt… Stop, stop I’m doing this."
> B. [B tries to make a link but can’t as A is opening a separate window] ”
>
> ***Group 17 (table)***

On the tablets condition the one focused participant was observed to still be able to make serious additions and leave the others to continue unproductively. While this was not seen to resolve the behaviour it did allow for some productive work to continue. The following quote demonstrates participant B making a link and typing a text input while participant A is off-topic, without it preventing her from working:

> “ A. [typing] "I want to link John Key to it!
> B. [makes a link, and is in the middle of typing] ”
>
> ***Group 17 (tablets)***

While productive disagreement and conflict can be beneficial to collaborative learning, by forcing members to evaluate others’ ideas as well as their own [10], unproductive disagreement as analysed above does not carry the same benefits. However in this study the researcher did not act as a teacher or mediator and attempt to stop any behaviour from occurring. As a result the amount of unproductive behaviour was likely to be higher than if a teacher or supervisor had been present and actively working to encourage productive work.

6.7.5.3 Summary

Conflicts in this study were observed fairly consistently across conditions. There were some differences observed in how these conflicts were managed across conditions. The tablets condition made it easier for participants who were trying to work productively to continue in spite of others in the group being distracted.

6.8 Conclusion

The results from Section 6.4 (CLM Framework analysis) and 6.5 (Time Off-Task) show that there is evidence in support of the theory that multi-touch tables facilitate more collaboration than laptops. Our analysis also does not demonstrate any significant difference between the multi-touch table and the networked arrangement of tablets. Some evidence has been provided which suggests that tablets may be able to facilitate more collaboration than laptops, shown through higher engagement and more group awareness vocalisations.

The system usability scale survey and qualitative data gathered after the completion of the three tasks indicates that the laptop was the most usable condition, being familiar, easy to type on and with fewer technical issues than other conditions. The results also showed no significant difference between the table and tablets in terms of perceived usability.

Based on the results from our CLM framework analysis both null hypotheses have to be rejected. When comparing the laptop to the touch table there are significant differences found in the quantity of collaboration, rejecting the null hypothesis $H_0 1$. Comparing the table and tablets conditions shows no significant difference in the quantity of collaboration, resulting in the rejection of the null hypotheses of $H_0 2$.

Chapter 7

Discussion and future work

This chapter discusses the results found in the user study. It seeks to explore potential explanations for the results and how these relate to previous research in the field.

7.1 Discussion

The results of the user study show that there were differences between the three conditions. The touch table could be said to provide a superior platform for collaborative work through high engagement and negotiation events. There were no significant differences observed between the tablets and the touch table in any of the numeric measures, although engagement was higher on the tablets and this was approaching statistical significance. However, whether the tablets are a superior collaborative platform than the laptop is debatable. Although the tablets showed a significantly higher level of engagement and number of joint awareness events than the laptop, they did not show a higher level of negotiation or suggestions - factors that R. Fleck et al define as mechanisms of collaborative behaviour [28]. This section seeks to discuss the results and their implications for using a networked tablets setup as an alternative to a touch table for collaborative work.

7.1.1 System Usability

One of the main questions that this thesis sought to answer was whether the tablet system provided a usable system and how this compared to the other two conditions. This subsection will discuss the relevant usability results for all systems and qualitative observations of interaction differences.

The results from the SUS survey presented an unexpected finding from the study. Overall, the participants perceived the laptop to be significantly more usable than either the touch table or the tablets. Observations made during the study were that the interaction with the laptop was more familiar and predictable, which may partly explain why the laptop was rated more highly than the other conditions. From the initial design research teachers also often reported that students strongly preferred typing on real keyboards which may have had an effect in this task. The touch table and the tablets show very similar usability scores (70/100, which is approximately the average SUS score). While there were many small interface differences between these two conditions the major difference was the bezels around the tablet edges. Although SUS scores are not diagnostic this does provide some evidence that the networked tablets arrangement was not highly disadvantaged by the bezels.

Results from the qualitative feedback also did not suggest that the tablets were highly different from the touch table regarding user interaction. Although more participants rated the touch table as their favourite condition, some users rated the conditions as equal in spite of this not being given as an option. One of the reasons for rating the touch table or tablets as a favourite (the ability to work at the same time) was given on both conditions. This provides a parallel to some of the insights gathered from the design probes, which indicated students enjoyed collaborative work more if the group worked well together. All groups made use of the entire space afforded by the tablets and seemed to understand the concept of the linked tablets.

However, there were still elements of the tablets system that caused issues. Two users reported in the post-study interview that they found the tablets harder to use because it was harder to tell which links were connected. This is illustrated in the quote below:

> “ "I thought the tablets were too glitchy and you couldn’t tell where links went." ”
>
> ***Group 14, Participant B***

It was also observed in the qualitative video analysis that four groups demonstrated some amount of ownership over their respective tablets. This is in contrast to the touch table where this ownership of space was not observed.

It seems likely that the networked tablets, arranged immediately next to each other, did provide a similar working space to the touch table. This type of system does have it’s own unique constraints, especially the bezels around the tablets, and applications need to take these into account. Although it was not explored in this thesis, the tablets also present a potentially more flexible tool as a platform for collaboration. By providing a device that students can use individually and together, this system may be able to provide better support for transitions between tabletop collaboration and external work as suggested by S. Scott et al in their system guidelines for co-located, collaborative work on a tabletop display [37]. This could, in turn, offer more options for supporting cooperative learning, which often requires a combination of individual and group work, and which research has shown to improve learning outcomes compared to unstructured collaborative work [13][5][63].

7.1.2 Concept map output

The concept map output scores showed no significance between conditions. This agrees with the similar number of suggestions observed across conditions in the CLM framework analysis, as any addition to the concept map was always accompanied by a suggestion. This is not an unexpected result as collaborative learning generally aims to improve quality of answers and learning of participants rather than increasing output. This measure was also likely to have been affected by the short time allowed for each task, which reduced the potential impact of collaboration.

7.1.3 Quantity of collaboration

The quantity of collaboration can be determined from the results of the video analysis using the CLM framework [28]. In this framework R. Fleck et al propose suggestions and negotiation as the actual collaborative behaviour, with joint awareness being the mechanism for organising this collaboration. In particular, negotiations are of interest as social interaction through discussion, disagreement and building on others' ideas is thought to be the mechanism for collaboration, leading to higher learning outcomes [10].

7.1.3.1 Suggestions

The number of suggestions given was similar and not significantly different across all conditions. This matches observations that were made during the study. Although participants often took turns on the laptop and had lower engagement when it was not their turn, they tended to make a high number of suggestions when it was their turn. On the touch table and tablets conditions this turn-taking behaviour was less common and suggestions were generally made more consistently, but at a lower rate, throughout the task.

7.1.3.2 Negotiation

The number of negotiations was significantly higher on the touch table condition than the laptop condition, which is in line with the findings of O. Shaer et al [30] who compared a multi-touch table to single- and multi-mouse laptop conditions. Qualitative observations suggest that this higher level of negotiation on the touch table was due to higher joint awareness of other members' actions than in other conditions. This high implicit awareness seemed to be due to the single text input and high engagement.

In this study, the tablets did not show significantly higher negotiation than the laptop. This seems to be a major issue with regard to the potential of the tablets to facilitate collaboration as a substitute for a touch table. From the results of the qualitative video analysis it seems that, in this context, the factor lowering the level of negotiation on the tablets condition seemed to be a lack of awareness of the text inputs of other group members, due to entering these textual inputs in parallel. This is in agreement with findings by S. Higgins et al [64], who qualitatively observed higher joint awareness leading to increased negotiation. It would seem to be somewhat in agreement with the findings of D. Stanton and HR. Neale in 2003 [65], who found that, when using multiple mice for a collaborative activity, participants often worked in parallel with low reciprocity (responding to others ideas). Although, in this case, the multi-touch capabilities of the touch table and tablets could be said to mirror the multiple mouse inputs, from the qualitative observations it seems that having multiple inputs tends to reduce negotiation if it lowers awareness of others' actions. This theory helps explain why the tablets were observed to have lower negotiation of text inputs but similar levels of negotiation of linking and images, which are more visible.

It seems likely that the low level of negotiation on the laptop condition was due to significantly lower engagement. Participants were less likely to be aware of what was being added due to this low engagement, and therefore less likely to negotiate these ideas.

7.1.3.3 Joint awareness

Joint awareness events were found to be significantly more common on the tablets condition than the laptop condition. However, it was observed in the qualitative video analysis, that implicit awareness of events was potentially lower in the tablets condition when compared to the touch table. In particular, the ability of participants to type individually seemed to lower implicit joint awareness, as students were more likely to focus only on their own screen rather than the surface as a whole. This seemed to necessitate a higher need for explicit group awareness utterances to coordinate the group. It does seem to demonstrate that the participants in this condition were aware of the lower implicit joint focus and recognised the need for the explicit coordination of the group.

This high level of joint awareness utterances around the tablets agrees with the findings of O. Shaer et al [30], who found that, when comparing a touch table to a single- and multi-mouse laptop, talk relating to group coordination was significantly higher in the touch table condition. In this study, the finding of joint awareness around the touch table disagreed with the O. Shaer study, as talk relating to group coordination (joint awareness) was not higher than the laptop. However, it seems likely that this was due to the high level of implicit awareness resulting from the limited text input of the touch table, which focused the group on a single point.

7.1.3.4 Engagement

Listening to others' suggestions and negotiations is an important part of working collaboratively. However, although these are included in the original CLM framework, they were not counted alongside suggestions and negotiations. It was decided that determining when a participant was listening, and how to count this discretely, would be too difficult to do consistently. Because of this, the alternative measure of total time off-task was noted. This inversely measures engagement with the task, but would also be expected to highly correlate inversely with the amount of time spent listening to others' suggestions and negotiations. For this reason, this measure can be seen as an essential part of effective collaboration rather than simply a measure of student interest.

The tablets showed significantly lower time off-task than the laptop, and a weakly significant lower time off-task than the touch table. The touch table showed a weakly significant lower time-off task than the laptop. This difference between engagement rates were likely due to novelty and turn-taking behaviour. None of the participants answered "yes" to having used a touch table before nor having used networked tablets in an ad-hoc arrangement. They did, however, all report using laptops in their regular schooling. Due to this, it is likely that some of the higher engagement can be accounted for due to the novelty of both systems. Based on the qualitative observations of turn-taking behaviour, this difference in engagement can also be accounted for partly by the lower engagement observed with participants not using the technology during periods of turn-taking. Similar to the turn-taking behaviour, which was commonly observed on the laptop, participants often lost engagement when others were typing on the touch table. While this was often observed in the groups that were classified as turn-taking, it was also observed in other groups on the table.

This high engagement rate on touch table and tablets is also a positive finding without considering its impact on collaboration. Engagement with the task is highly desirable for individual learning and for teachers for whom it reduces the need to mitigate problems associated with lack of engagement.

7.1.4 Quality of collaboration

In the video analysis with the CLM framework each measure was only coded if the topic was relevant to the task, therefore providing some measure of basic quality. By conducting an observational video analysis according to the elements of behaviour framework it was possible to see how different collaborative behaviour occurred, and provide insight into differences in collaboration quality between conditions. This analysis is limited to being descriptive in nature and can only offer generalised insight. Equality of participation was also analysed, as previous research has suggested that this may be a good indicator of productive collaborative learning [66][8][67].

7.1.4.1 Observational video analysis

Based on the Vygotskian based theory of collaboration, quality of collaboration is generally thought to be related to the number of conflicting ideas that are discussed and resolved [10]. Therefore, the negotiation, reciprocal and cumulative behaviours are of particular interest in this study.

Based on the observations of reciprocal behaviour, discussion requires joint awareness of the idea being added, to catalyse discussion. In particular, vocalisation before input seemed more effective than simply joint awareness without vocalisation. This may have been due to vocalisation sending an implicit signal to the group that the author of the idea was seeking feedback or, at least, confirmation.

Cumulative behaviour could be seen as the ultimate goal of collaborative work [68]. It represents extended discussion which builds on others' ideas and can lead to a collective group answer which is superior to any individual answers. Cumulative behaviour was not commonly observed in the groups, possibly due to the short time given for task. However, it seemed that groups which showed high levels of discussion also tended to show higher levels of cumulative behaviour. Therefore, it seems likely that the technologies which encourage groups to negotiate and discuss ideas would also be successful at encouraging extended discussion and cumulative discussion, both of which can be regarded as high quality collaboration.

7.1.4.2 Equality of participation

High equality of participation has previously been stated to be an indicator of effective collaborative learning [8]. Analysis of equality between conditions failed to show a statistically significant difference. This is somewhat consistent with other papers, which report that when comparing a single-touch table to a multi-touch table there is no difference in equality of participation [33], and no difference in equality between a laptop and multi-touch table [30]. The qualitative analysis shows that turn-taking is a common behaviour on the laptop and this appeared to result in less effective collaboration due to disengagement of participants and lower discussion. It was observed that turn-taking led to inequitable participation while each turn was occurring, however in this study inequality of total contributions were measured. Based on the qualitative observations, groups that were classified as turn-taking tended to try to ensure every member had a fair turn at some point during the task. This matched the insight gained in the initial design research which indicated that students placed a lot of emphasis on fair allocation of work. However, this likely led to the overall inequality measure showing similar levels of inequality as the other conditions.

This measure of equality of participation offers no evidence that the quality of collaboration was different between conditions and, although the observational video analysis suggests that higher levels of negotiation as was seen on the touch table may lead to, or represent, higher quality collaboration, this link is unclear. It therefore seems that the quality of collaboration, when collaboration did occur, did not vary between conditions.

7.1.5 Limitations of study

The data gathered in this study was in taken in a naturalistic, classroom-like setting, and the researcher aimed to analyse human behaviour in this setting. In spite of efforts to reduce external variables through a within-subjects study design, the data could be described as noisy. This made it more difficult to accurately determine the impact of technology on collaborative behaviour, as the behaviour of young students working together is affected by factors that are difficult to control for, such as prior relationships, academic ability, motivation or boredom with the task. It is possible that this study may have therefore been more prone to type 2 errors. To reduce this possibility, larger data sets would be needed.

Despite the naturalistic setting the researcher did not attempt to act as a teacher. Participants were not actively encouraged to stay on task or given help with the content of the task, so these results may be different to those that would be demonstrated in a real classroom.

The study altered multiple variables between conditions, as shown in Table 5.1. This makes it difficult to attribute the findings of the study to particular variables. The findings should be treated with caution as they represent the differences found between the specific conditions used in this study rather than generalisable rules for table top collaborative work.

The school used for the study was also in the process of transitioning to an Innovative Learning Space (previously called modern learning environment), in line with recommendations made by the New Zealand Ministry of Education [69]. This style of teaching has a focus on collaboration, and may have resulted in the students performing better at the collaborative tasks than they otherwise would have.

In this study the engagement with the tablets was significantly higher than the laptop and weakly significantly higher than the touch table. The touch table was weakly significantly higher than the laptop. This may be due in large part to the novelty of these devices, and a study completed over a longer time period may reveal that this is reduced as the novelty of the technology wears off.

This study also makes use of subjective interpretations of data. Efforts were made to reduce the bias that this may present, however this may still be a source of bias in the study.

7.1.6 Summary

This evaluation has analysed the differences between three conditions: a laptop, a touch table and a networked arrangement of tablets. All of these ran the same software, a web-based concept mapping task. Of particular interest is the comparison between touch table and tablets to determine whether the tablets arrangement is effective in replicating some of the collaborative benefits of touch tables that have been previously demonstrated in the literature. There was no significant difference in collaboration found between the touch table and the tablets, however, while the touch table demonstrated significantly higher levels of negotiation than the laptop, the tablets did not. Based on qualitative observations of how negotiation occurred during the task it seems likely that this slightly lower level of negotiation on the tablets could be mitigated through their design, for example: requiring all group members to "accept" any text input before it is added. The following section will outline future work to improve upon the system design evaluated in this thesis.

7.2 Future Work

Although the results of the evaluation demonstrated benefits from using tablets, such as high engagement and similarities with the touch table, there is potential for further work to improve upon the design presented here. A sensible next step would be to make some small changes based on learnings from the evaluation. For instance, it seems necessary to create more awareness of what others in the group are typing, to encourage negotiation and discussion. This could potentially be achieved by requiring all members of the group to confirm a text input once it is typed, and before inserting it, through a voting mechanism. Further refinement could also be considered to reduce the risk of individuals claiming "ownership" over particular tablets. This could possibly be achieved by building in an induction tutorial that encourages all users to touch all tablets.

In order to confirm the findings of this study, further studies using larger data sets would be needed. In particular, studies that involve a wider age range, socio-economic status and schooling style may provide important insights as to whether the findings presented here are generalisable to a wide population.

It would also be worthwhile conducting studies over longer time periods, enabling the use of more typical individual learning outcome measures based on formal testing. However, learning outcomes may be difficult to demonstrate clearly. The link between collaboration and higher individual learning is clear, as well as the benefit of improving this collaboration through more structured cooperative activities. It would therefore make sense that improving collaborative or cooperative learning through the use of technology would improve learning outcomes, however this may be a small effect and difficult to clearly demonstrate.

Based on the promise of the prototype system tested here it seems worthwhile exploring the incorporation of more of the attributes of the original envisaged system (as described in Figure 3.6). For example, using the tablets system to support not only collaborative work but also cooperative learning. Cooperative learning exercises like "Jigsaw", where students learn about a topic in an "expert" group then return to their original group to aggregate learning, could be effectively supported with this system of networked linked tablets. The use of spatial interactions between tablets, as proposed in the envisaged system, could also be explored to determine their effectiveness in enabling users to navigate larger volumes of information than was required in this study.

This envisaged system also explored the incorporation of tools for teachers. Teacher support would be necessary for a commercial application of this technology, therefore future work that develops, refines and tests the effectiveness of a teacher control panel would be beneficial.

Inter-group interaction could also be explored. For example, different groups could collaboratively learn about the different parts of a topic - for instance, the water cycle - with the various parts flowing to the next group. Ideas from mobile learning could also be explored, such as creating location-aware learning situations based on GPS data.

Chapter 8

Design Guidelines & Conclusion

8.1 Design Guidelines

These design guidelines provide a short list of things to be aware of when designing different applications for similar tablets systems to maximise collaborative behaviour in students between ages eight to twelve. They are based on qualitative observations taken from this study.

- Ensure that group focus is drawn to events, especially if these events are not always vocalised. For example this could be done either through an addition being highly visible (in this case adding images), or a more explicit method such as displaying the addition on all screens.
- Multiple input sources should be carefully considered to ensure that they do not reduce group awareness, as per the above guideline.
- If tablets are moved or rotated the application should automatically adjust to maintain the concept that the tablets are windows onto the canvas. In this case, the system did not do this, and by rotating the tablets users could cause links to not align correctly, causing confusion.
- Shapes crossing the boundaries of the tablets should be straight (rather than curved) as these are easier to follow when crossing the bezels. Figure 8.1 shows this effect. Area **1** shows links not aligning and area **2** shows the issue with curved elements crossing the edge.
- Consistent with our initial specifications, do not locate any permanent menus or buttons along edges that are next to other tablets.

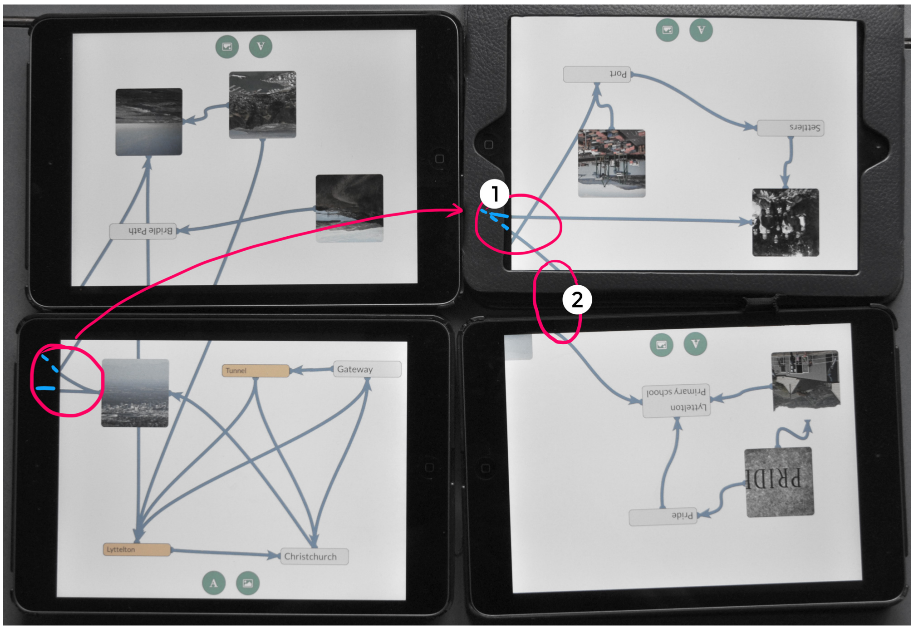

FIGURE 8.1: Shows tablets that have been moved and rotated causing links to not connect correctly.

- Do not digitally space the tablets to match bezel size. Objects should appear on the next tablet as soon as they are dragged off one, rather than being "hidden" by the bezel. This reduces the chance for objects to be lost between tablets.
- Objects on screen must be normalised to real-world display size, rather than pixels, to ensure they stay at the same size when dragged between tablets.
- Allow flicking actions to pass objects between tablets.

8.2 Conclusion

Around the country many primary schools are investing in tablet computers as part of their core IT resources. These powerful, mobile computers offer developers many flexible options in creating engaging and effective learning technology through the use of cameras, sensors and connectivity. A trend can be seen in recent literature showing the benefits of touch table computers at facilitating collaborative learning. However, this technology is currently still expensive and out of the price range of many schools. Using tablets to recreate this collaborative benefit seems sensible as it places low additional cost on schools who have already invested in multiple tablets and uses technology that is well supported for school usage. Creating applications that sync data between devices also continues to become easier to develop with the emergence of Javascript frameworks like react.JS[1] and Meteor[2].

[1] `http://facebook.github.io/react/`
[2] `www.meteor.com`

To investigate the potential of tablets to recreate this collaborative benefit, a prototype tablets system consisting of four networked tablets was created. In this system each tablet made up $1/4$ of the total screen area and objects could be dragged between screens. This mimicked the surface of a touch table. An evaluation of the system was carried out comparing it to a laptop and touch table condition. These evaluations sought to determine whether the touch table and tablets provided a similar interactive working space and whether the quantity and quality of collaboration was similar in both conditions.

Comparing the quantity of collaboration between the laptop and the touch table showed that the touch table facilitated more collaboration. This is consistent with previous literature on collaboration around touch tables. It builds on the evidence that touch tables could be beneficial to schools where collaboration is regarded as an important learning paradigm and skill.

The collaboration quantity between touch table and tablets showed no significant difference in any area, although some of the qualitative observations from the video analysis presented differences in group structure on these platforms. In particular, the multiple text inputs available on the tablets seemed to occasionally lead to less joint group awareness. This is consistent with previous research on using touch tables and similar technologies for supporting collaboration. This similarity in quantity of collaboration is good evidence for the suitability of the tablets system as a substitute for a touch table.

The collaboration quantity between tablets and laptop was not as conclusive. Engagement with the task was higher on the tablets condition, which is considered an important part of effective collaboration and certainly something very important to teachers. However negotiation was not shown to occur significantly more than on the laptop. It is thought that this could be improved with slight modifications to the design based on our qualitative observations of how and why negotiation and discussion occurred. However, this would need further investigation to demonstrate.

Overall, evidence has been presented that supports the idea that a networked system of tablets may provide a viable alternative to touch tables for collaborative work. Given their low cost and existing usage in schools, this presents a practical way in which collaborative learning that incorporates technology can be improved.

Appendix A

Appendix

A.1 SUS details

Figure A.1 shows the modified SUS survey which was filled out by the participants at the end of each condition. From the initial design research done, it was clear that app was a word familiar to children of that age/area, therefore it was substituted for the word system which was thought may be confusing especially to the younger students (eight - ten years). It was made clear to the participants that the 'app' referred to both the technology and the software in this case.

A.2 Image accreditation

Figure 3.4 features YIA 2014 Teachers, a photo by Locus Research available under the Attribution-ShareAlike 2.0 Generic licence.

Figure 3.5 features firstdayofschool, a photo by USAG Livorno PAO available under the Attribution 2.0 Generic licence.

Figure 2.1 features Feedback after a workshop, a photo by Wesley Fryer available under the Attribution 2.0 Generic licence.

Questionnaire	Strongly Disagree				Strongly agree
I would like to use this app frequently	1	2	3	4	5
I found the app very complicated	1	2	3	4	5
I thought the app was easy to use	1	2	3	4	5
I think that I would need the help of a technical person to be able to use this app	1	2	3	4	5
I found the different parts of this app worked well together	1	2	3	4	5
The app often did not work how I expected it to	1	2	3	4	5
I think that most people would learn to use this app very quickly	1	2	3	4	5
I found the app very tricky and slow to use	1	2	3	4	5
I felt very confident using the app	1	2	3	4	5
I needed to learn a lot of things before I could get going with this app	1	2	3	4	5
I felt that I contributed well to the group	1	2	3	4	5
I felt included in the group	1	2	3	4	5

FIGURE A.1: System usability scale altered for younger users

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